METAgenierie 2017 : Principes et applications des métamatériaux acoustiques pour l'ingénierie. 2-7 juillet 2017, Oléron

Techniques expérimentales pour les métamatériaux acoustiques

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LABORATOIRE ONDES et MILIEUX COMPLEXES
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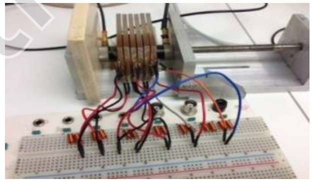
Course outlines

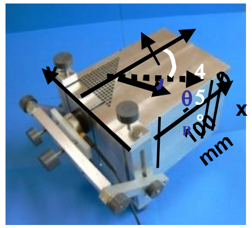
PART 1 : Observation and characterisation of forbidden bands in a PC.
Experimental Band structure determination

• 1D Phononic Crystal made of a stack of rectangular plates. Particular case of piezoelectric plates



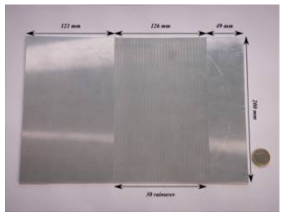
•2D square array of steel cylinders embedded in an epoxy matrix.

PART 2 : Experimental demonstration of the negative refraction in a solid PC.
Waves with opposite group and phase velocities



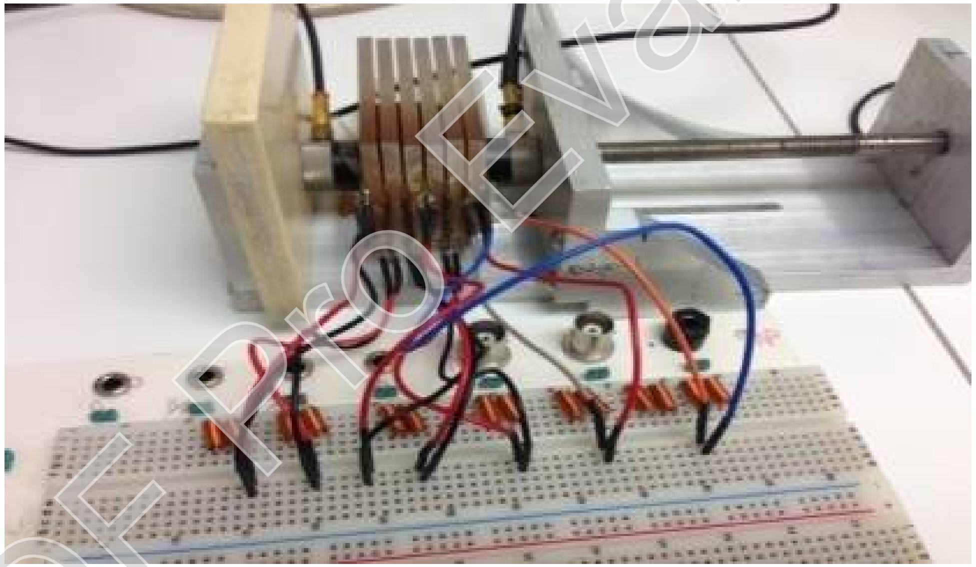
• Negative refraction in a solid phononic crystal

• Lamb waves in a plate with periodic corrugation



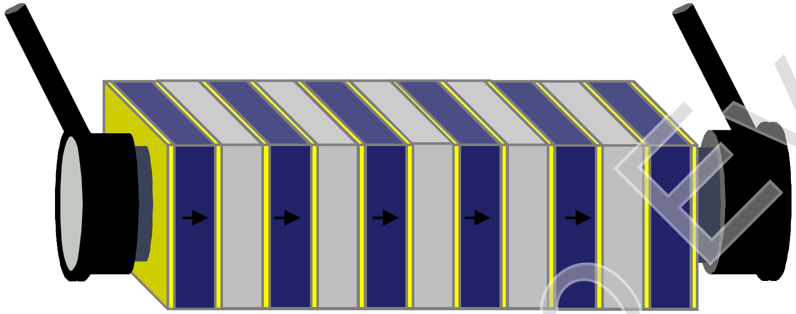
PART 1 : Observation and characterisation of forbidden bands in a PC. Experimental Band structure determination

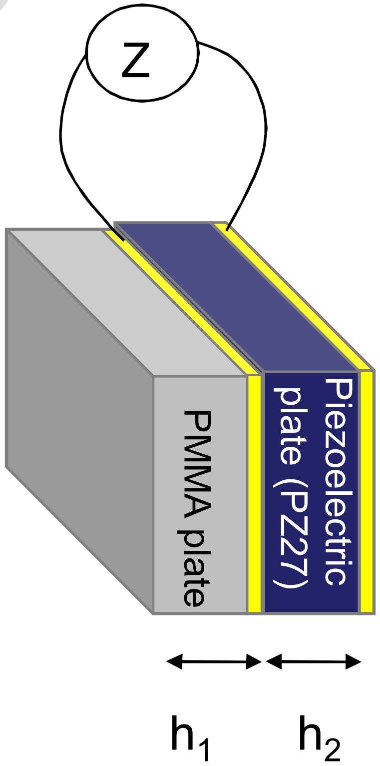
1D Phononic Crystal made of a stack of rectangular plates. Particular case of piezoelectric plates



Propagation through a stack of plates

1D phononic crystal composed of
alternating piezoelectric and PMMA plates





Elementary cell

Propagation through a stack of plates

Elementary cell

$$\begin{cases} T_j = c_{ij} S_i - h_{ij} D_j \\ E_j = -h_{ij} S_i + \beta_{ij} D_j \end{cases}$$

The dispersion relation is obtained by using the **Bloch-Floquet** relation and the piezoelectric constitutive equations

T et S :	Mechanical stress and strain
E et D:	Electrical field and displacement
c :	Elastic constant
β :	Dielectric permeability
h :	Piezoelectric constant

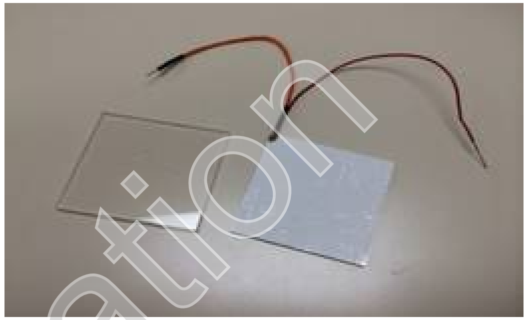
$$\cos k(h_1+h_2) = \frac{\cos(k_1h_1)\cos(k_2h_2) - \frac{1}{2}\left(\gamma+\frac{1}{\gamma}\right)\sin(k_1h_1)\sin(k_2h_2) + \frac{\alpha}{\gamma}\left(\sin(k_1h_1)\left(1-\cos(k_2h_2)\right) - \gamma\cos(k_1h_1)\sin(k_2h_2)\right)}{1-\alpha\sin(k_2h_2)}.$$

(Thèse de Sébastien Degraeve, 2013 (IEMN, Lille))

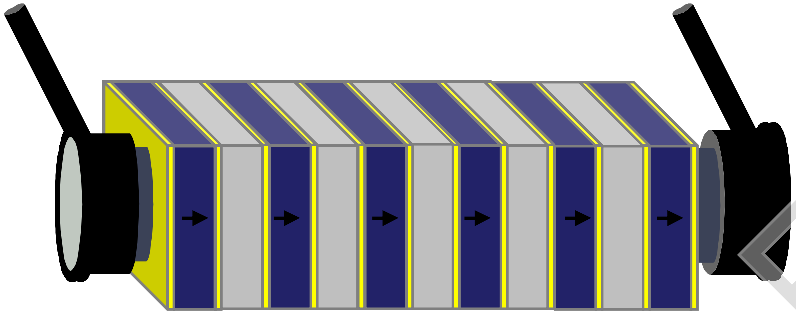
In this relation, $\alpha = \frac{h_{33}^2}{C_{33}^D\left(\beta_{33}^S + j\omega Z\right)}$. includes the electric boundary conditions.

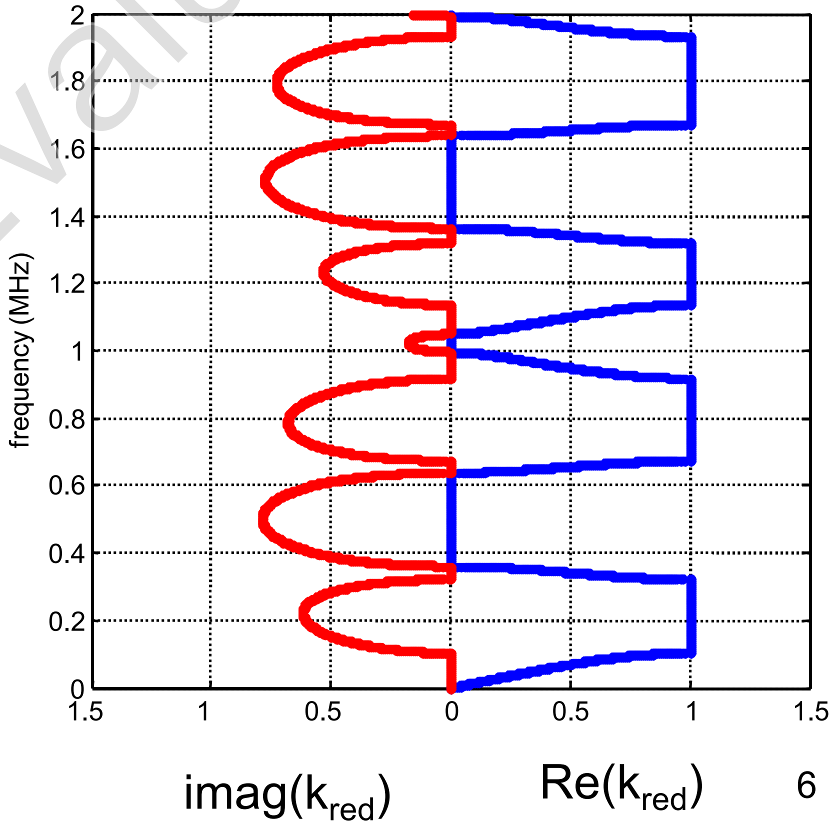
Depending on the electrical impedance charges Z connected on the piezoelectric plates, the band structure can be modified.

Propagation through a stack of plates



1D phononic crystal composed of alternating piezoelectric and PMMA plates

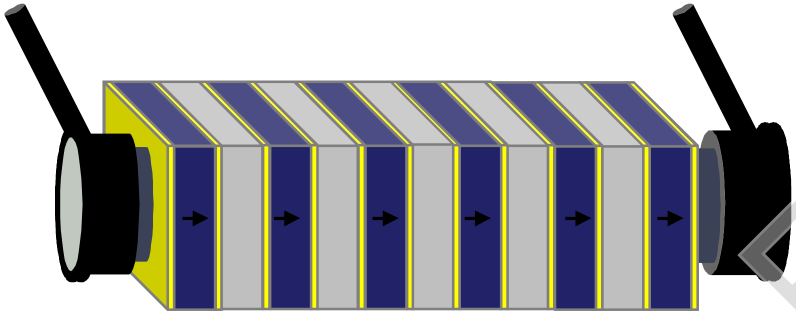




How to get experimentally both the band structure and the amplitude transmission coefficient through a slab of PC ?

Propagation through a stack of plates

1D phononic crystal composed of alternating piezoelectric and PMMA plates



For a sake of simplicity, we considere a harmonic plane wave transmitted through a thickness d_n of PC:

$$s(t) = A\ e^{j(k'_x d_n - \omega_0 t)}\ e^{-k''_x d_n}$$

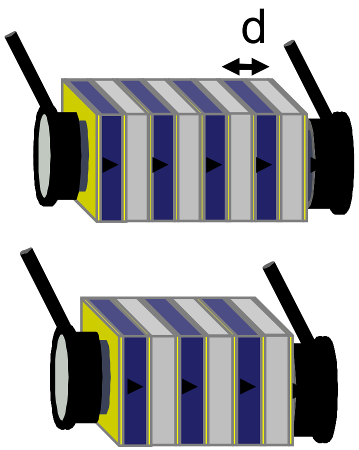
How to get experimentally both the band structure and the amplitude transmission coefficient of the waves through the PC ?

With complex wave number

$$k_x = k'_x + jk''_x$$

Propagation through a stack of plates

Experiments : aquisitions with respectivelly 1,2,3 and 4 layers



transmitted signal through the stack. Pulse excitation

Temporal signal $s_{n+1}(t)$ → FFT → $$F_{n+1}(j\omega) = F(j\omega)\ e^{jk'_x(n+1)d}\ e^{-k''_x(n+1)d}$$

Temporal signal $s_n(t)$ → $$F_n(j\omega) = F(j\omega)\ e^{jk'_x nd}\ e^{-k''_x nd}$$

$$\underline{Q} = \frac{F_{n+1}(j\omega)}{F_n(j\omega)} = e^{jk'_x d}\ e^{-k''_x d}$$

In previous expressions, F(jω) depends on the pass band of the transducers, the transmission at each interface, ….

- The real part of the wavenumber (dispersion)

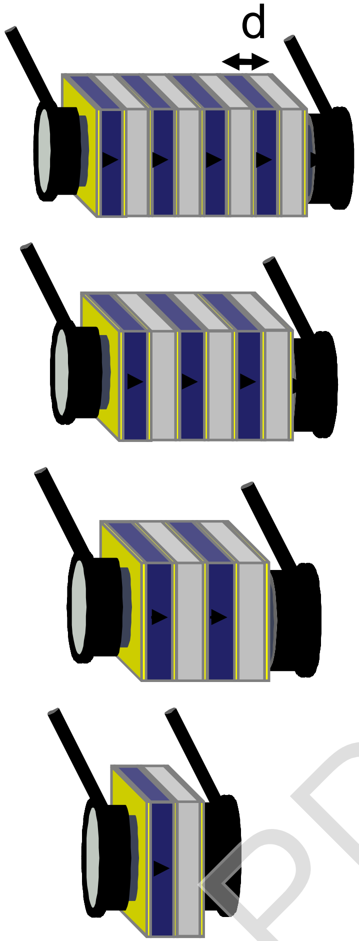
$$k'_x = \frac{\arg(Q)}{d}$$

- The imaginary part of the wavenumber (attenuation)

$$k''_x = \frac{-\ln|Q|}{d}$$

Propagation through a stack of plates

Experiments : aquisitions with respectivelly 1,2,3 and 4 layers



transmitted signal through the stack. Pulse excitation

FFT

Temporal signal $s_4(t)$ → $F_4(j\omega)$

Temporal signal $s_3(t)$ → $F_3(j\omega)$

Temporal signal $s_2(t)$ → $F_2(j\omega)$

Temporal signal $s_1(t)$ → $F_1(j\omega)$

$$\underline{Q} = \frac{F_{n+1}(j\omega)}{F_n(j\omega)} = e^{jk'_x d}\, e^{-k''_x d}$$

$$k'_x = \frac{\arg(Q)}{d}$$

$$k''_x = \frac{-\ln|Q|}{d}$$

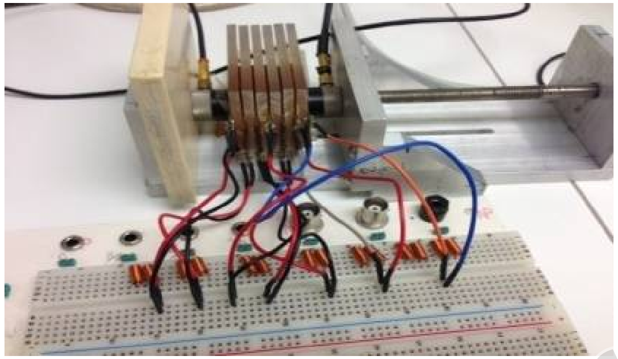
Propagation through a stack of plates

Frequency tunability of Phononic crystals

MIRAGES ANR-12-BS09-0015 project : Active metamaterials and phononic crystals controlled by electric and magnetic fields

Partners: IEMN CNRS 8520 (Lille, France), Thales RT, I2M (Bordeaux), LOMC UMR CNRS 6294, GREMAN UMR 7347 (Tours, France).

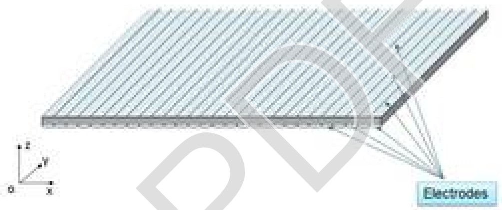
- 1D piezoelectric phononic crystal



PhD Thesis, Sid Ali Mansoura
Collaboration with
Anne-Christine Lhadky-Hennion, Bertrand Dubus
IEMN, UMR 8520 CNRS, Lille, France

Mansoura et al, Smart Mater. Struct. 24 (2015)

- Lamb wave propagation in phononic piezoelectric plates



PhD Thesis, Nesrine Kherraz
Collaboration with
Franck Levassort, Lionel Haumesser.
GREMAN, UMR 7347 CNRS, Tours, France

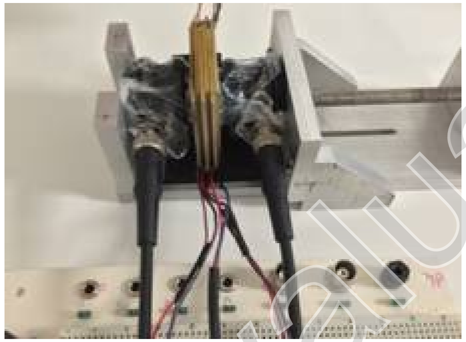
Kherraz et al, Appl.Phys.Lett 108, 093503 (2016)

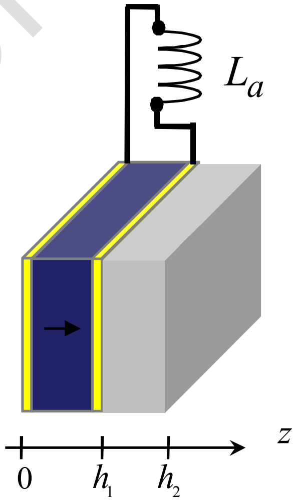
Propagation through a stack of plates

Piezoelectric Phononic Crystal connected to inductances

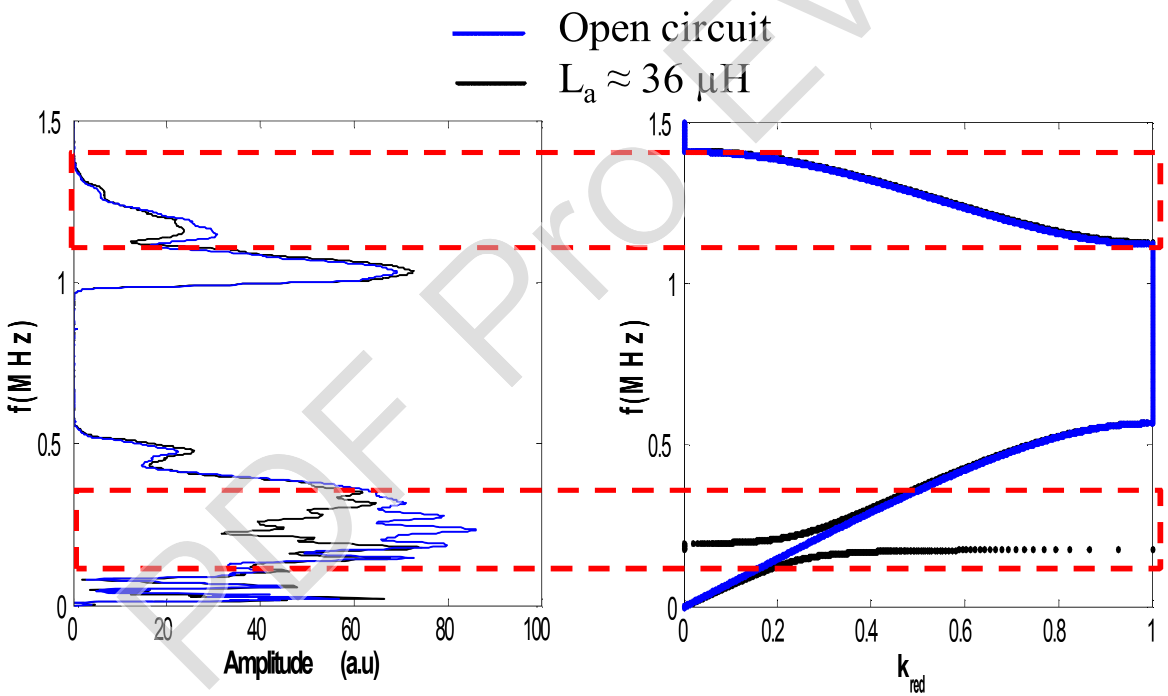
❑ Hybridization gap: experimental measurments

Phononic crystal:
stack of piezoelectric plates PZ27 (50mm*50mm) and et de plaques de plexiglass





❑ Opening a gap in LF range



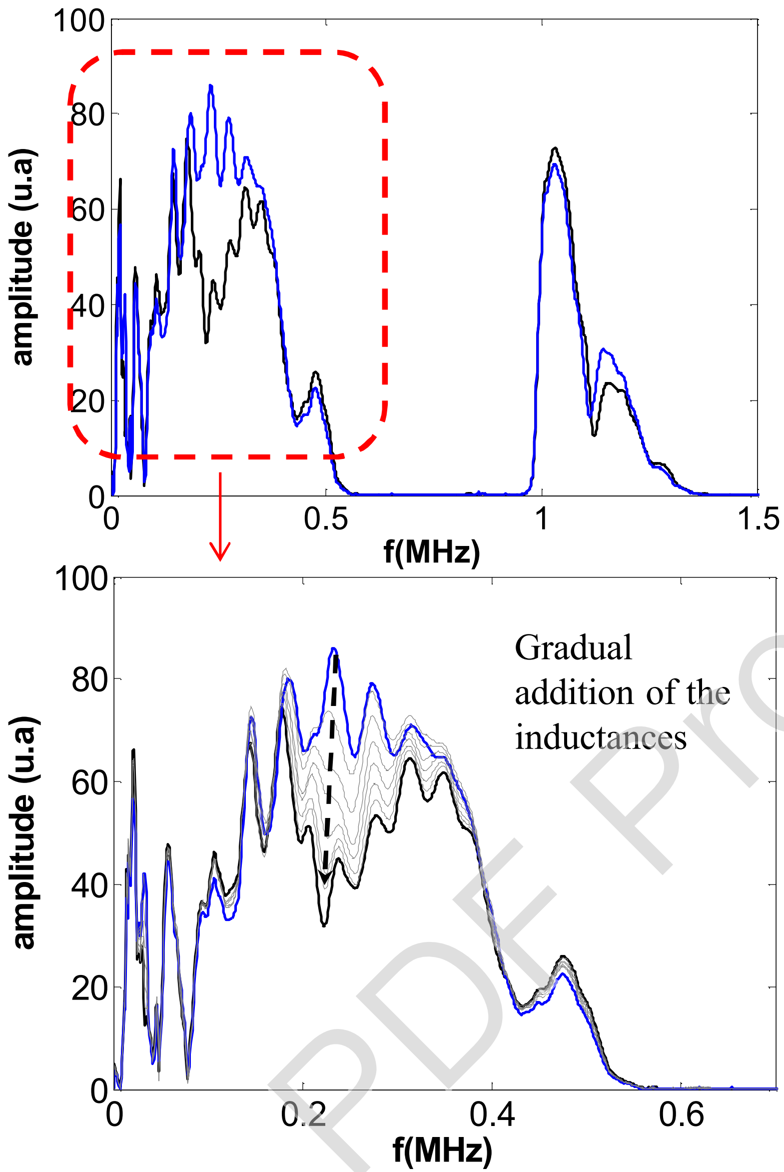
New band gap due to the electrical resonance

$$f_{elec} = \frac{1}{2\pi\sqrt{L_a C_0}}.$$

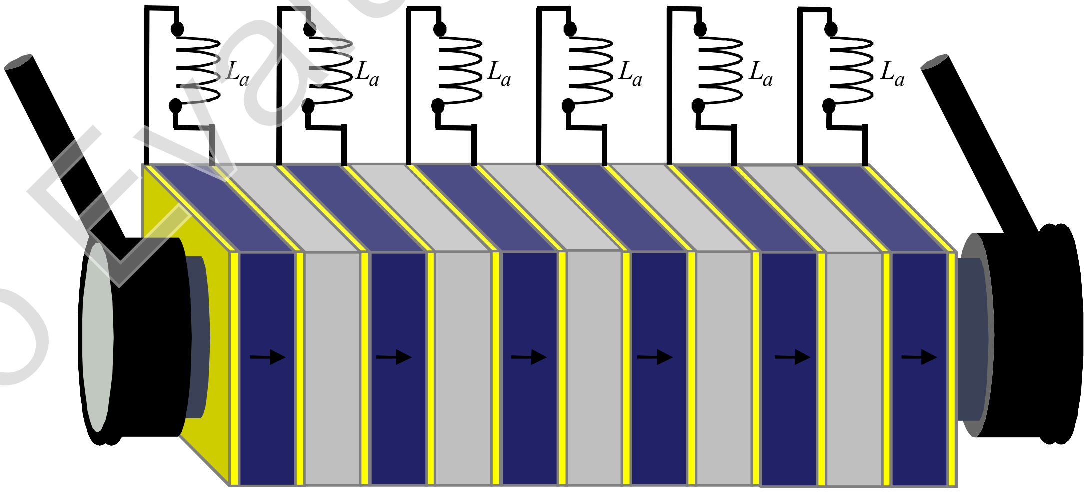
C_0 : Static capacitance of the piezo plate

Propagation through a stack of plates

Piezoelectric Phononic Crystal connected to inductances



Experimental transmission through the PC connected to the inductances



Receiver Transducer

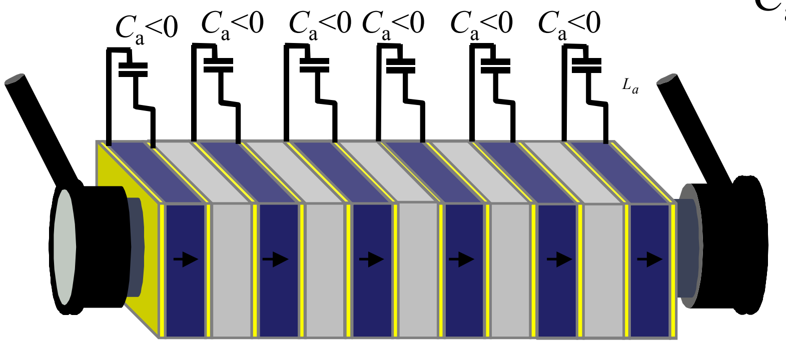
Emitter Transducer

Propagation through a stack of plates

Piezoelectric Phononic Crystal connected to negative capacitances

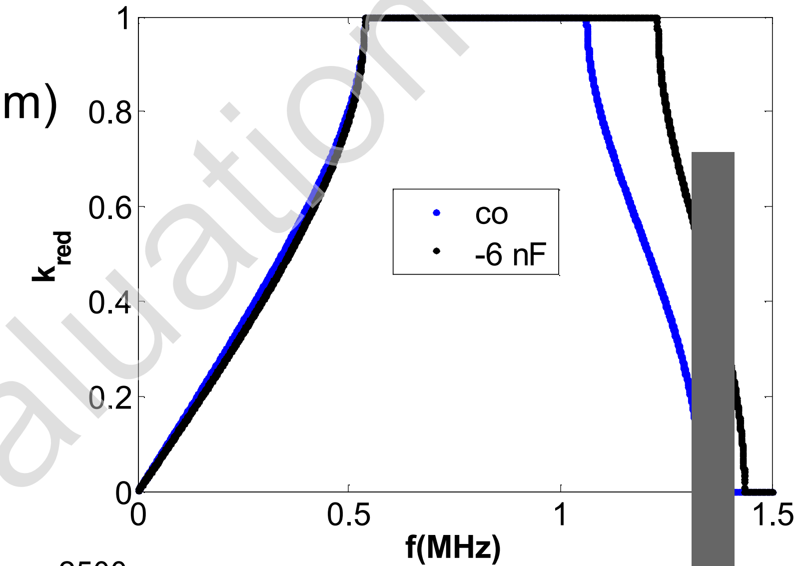
1D phononic crystal composed of alternating piezoelectric (PZ27) and PMMA plates ep=0.5mm) (6 elementary cells)

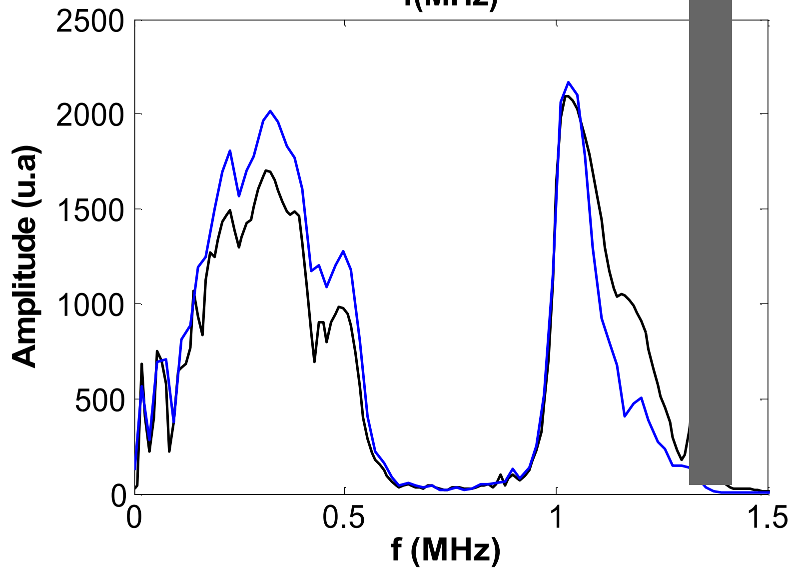
$C_a = -6\ \text{nF}$



emitter

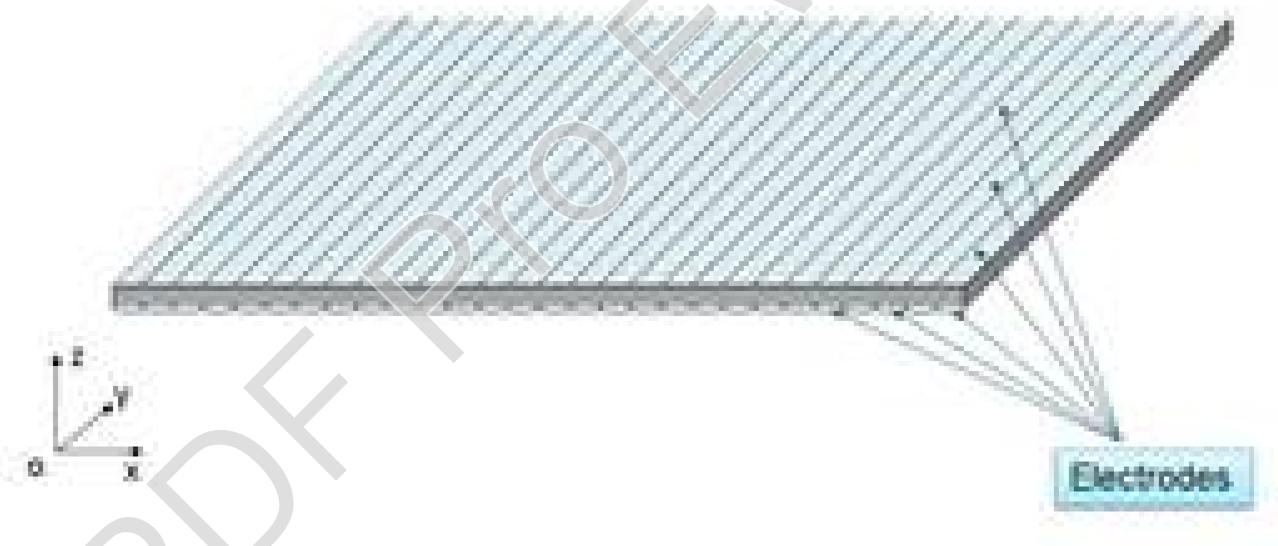
Receiver





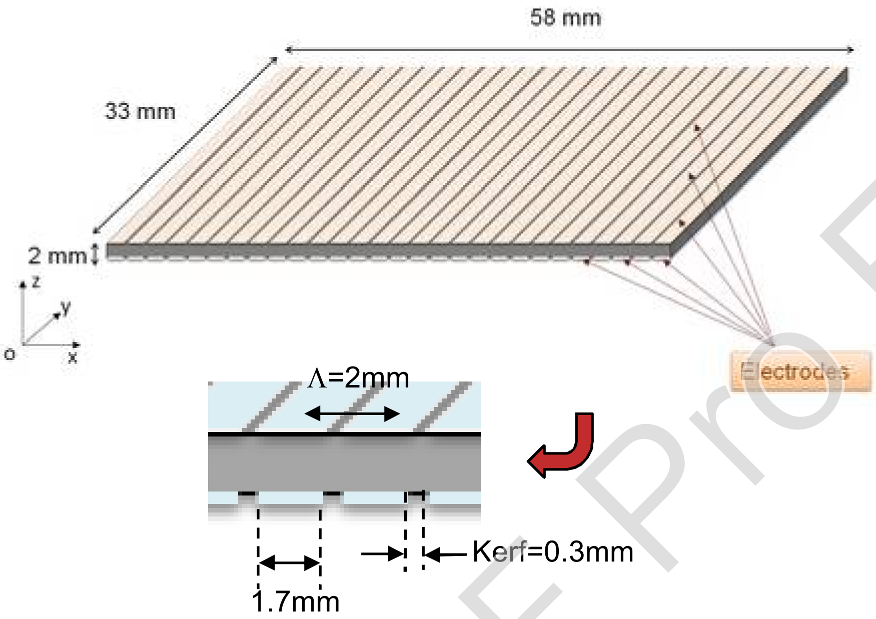
Piezoelectric PC plate

Lamb wave propagation in phononic piezoelectric plates



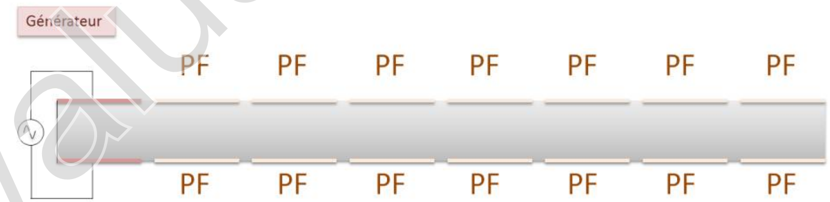
Experimental implementation of the piezoelectric PC plate

Homogeneous piezoelectric plate (PZ26)

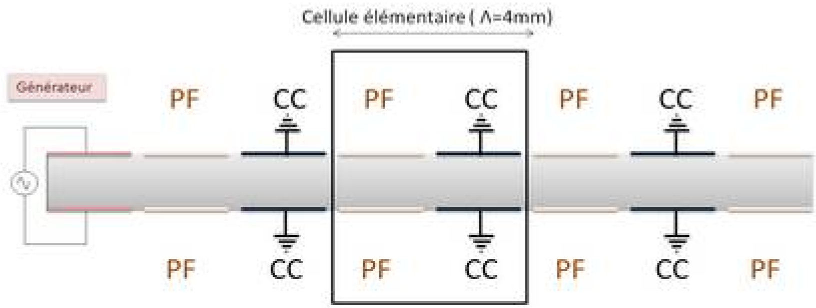


Configuration 1

PF : Floating potential
CC : short circuit

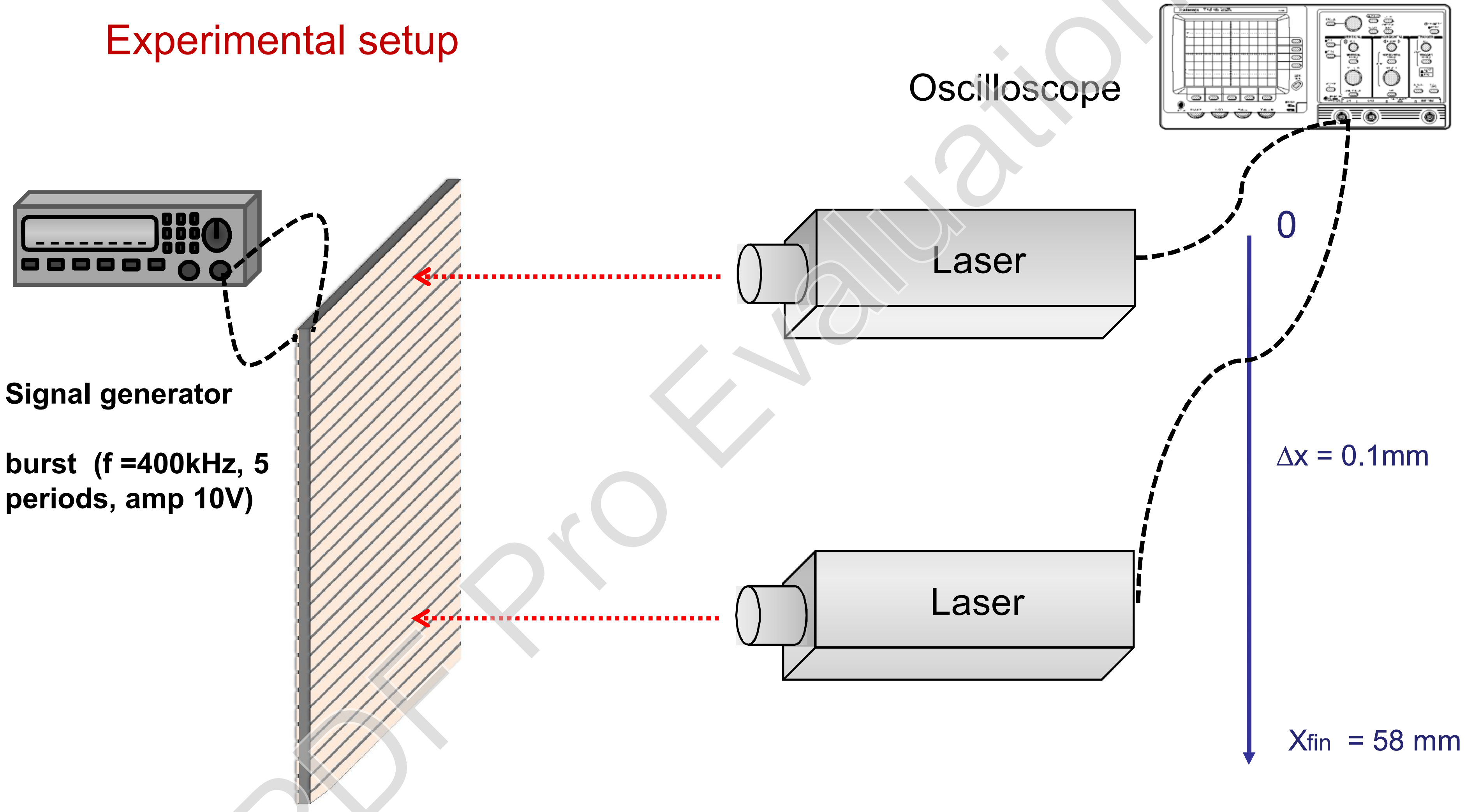


Configuration 2



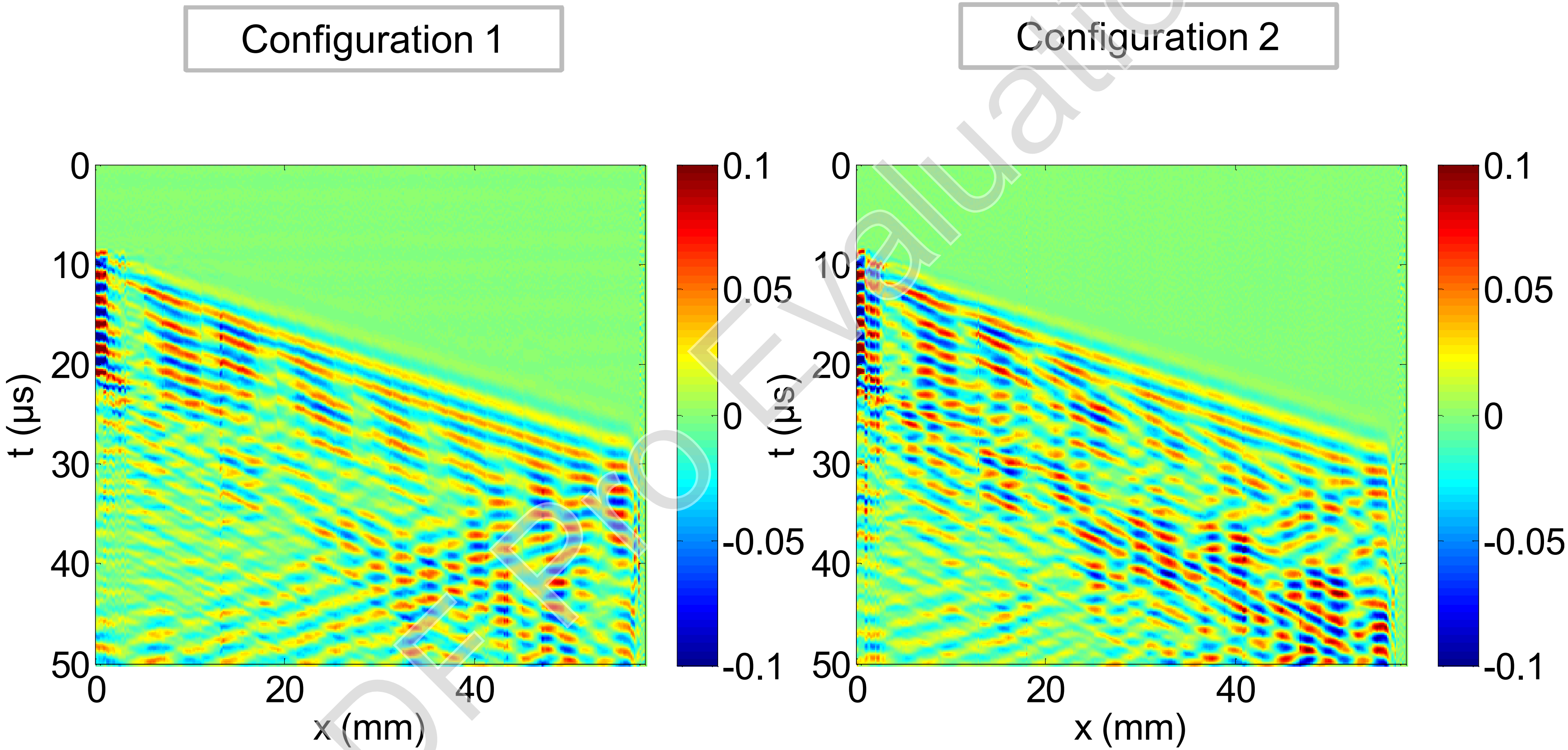
Piezoelectric PC plate : experimental study

Experimental setup



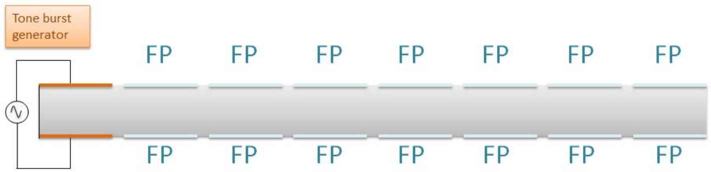
Piezoelectric PC plate : experimental study

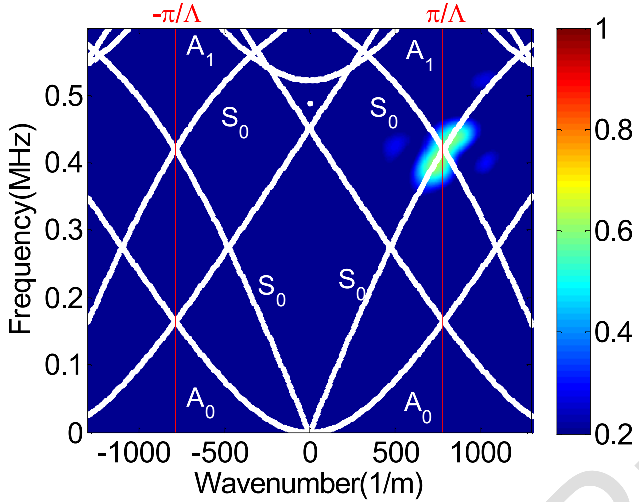
Temporal signals



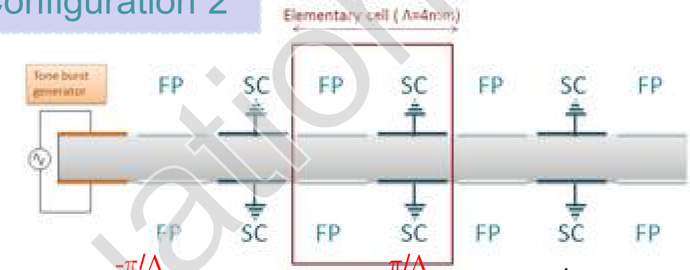
Piezoelectric PC plate : experimental study

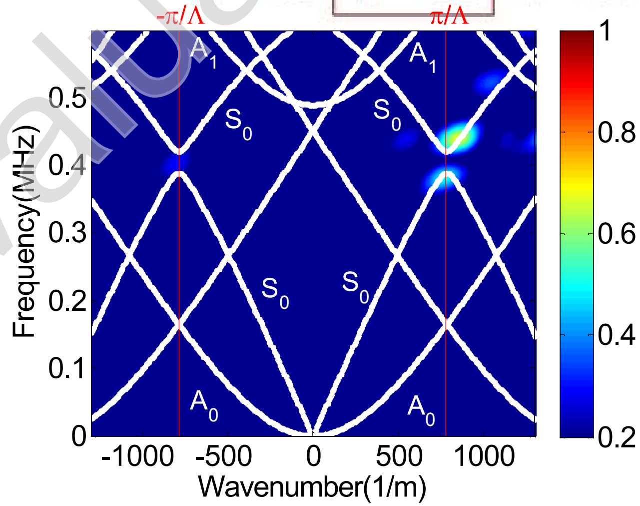
Configuration 1



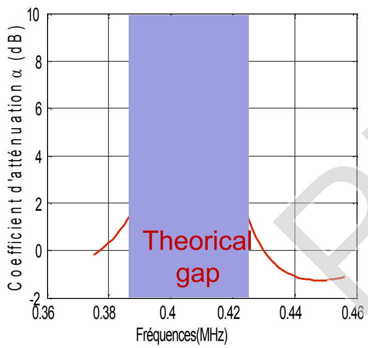


Configuration 2





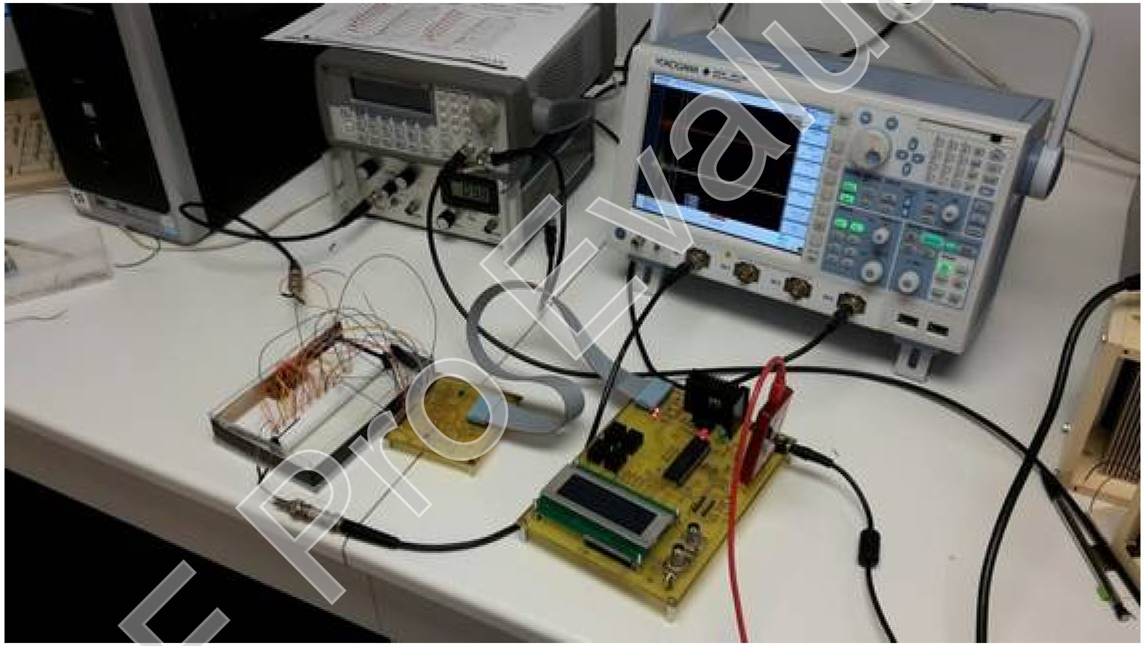
Attenuation coefficient



$$\alpha = 20\log\left(\frac{\text{amplitude } A_0 \text{ Config.1}}{\text{amplitude } A_0 \text{ Config.2}}\right)$$

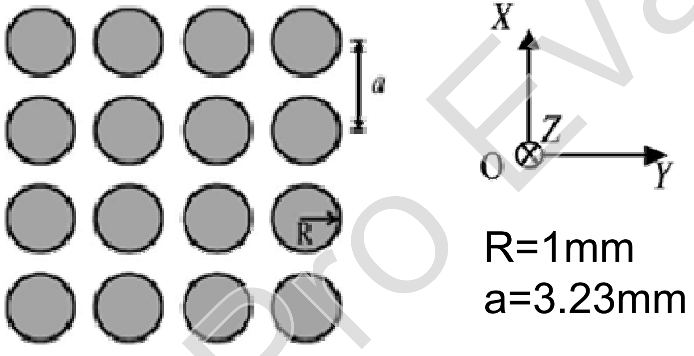
Attenuation of 10 dB for a length correponding to 10 elementary cells at f=408kHz

• Tuning in real time the the EBCs thanks to a microcontroller and controlled switchs



Square array of steel cylinders embedded in an epoxy matrix.

Présentation de la structure périodique étudiée

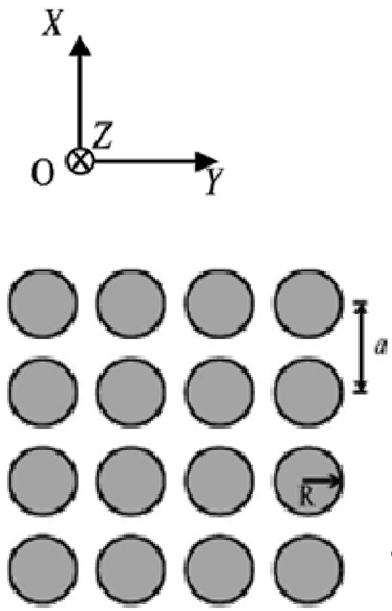


R=1mm
a=3.23mm

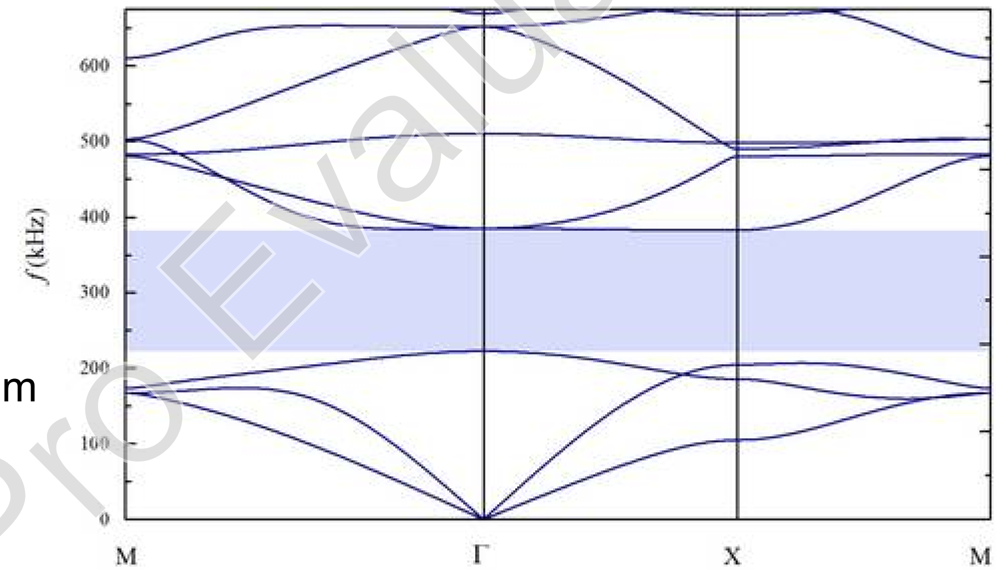
Square array (lattice constant a=3.23 mm) of steel cylinders (diameter D=2 mm) embedded in an epoxy matrix.

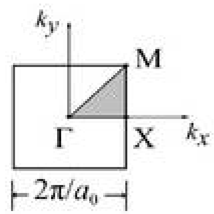
Square array of steel cylinders embedded in an epoxy matrix.

Band structure (only modes in the plane perpendicular to the inclusions are shown). Layered Multiple Scaterring Method, (R. Sainidou)



R=1mm
a=3.23mm



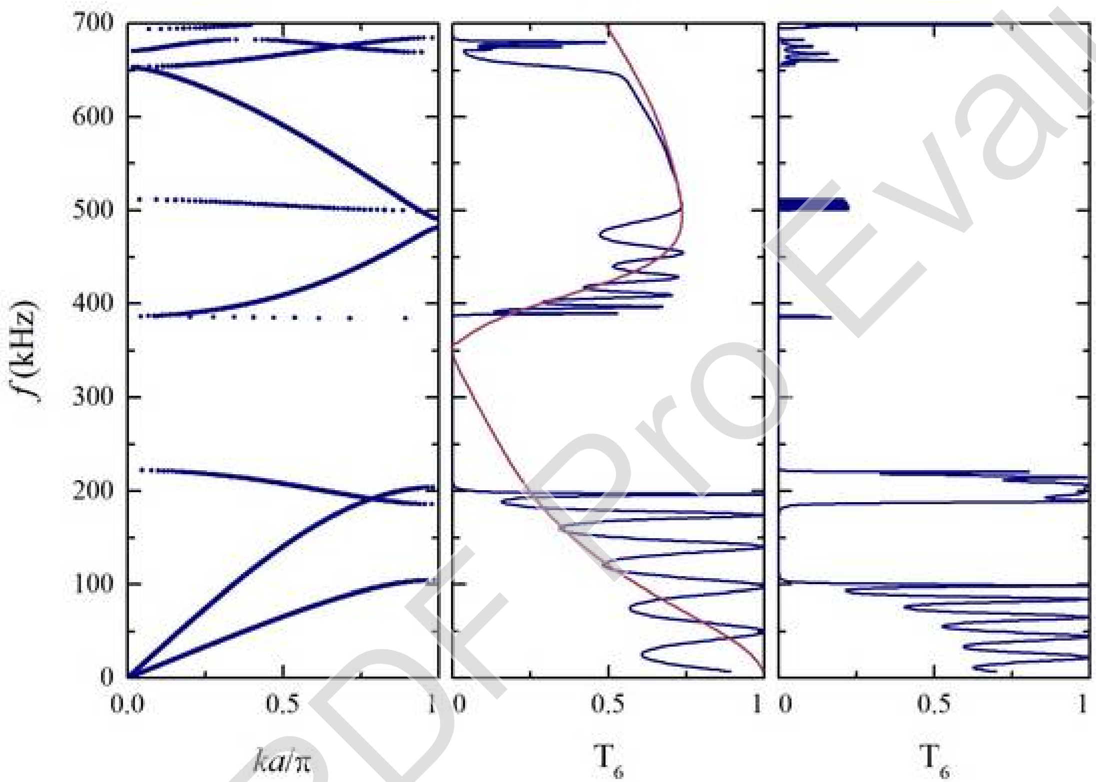


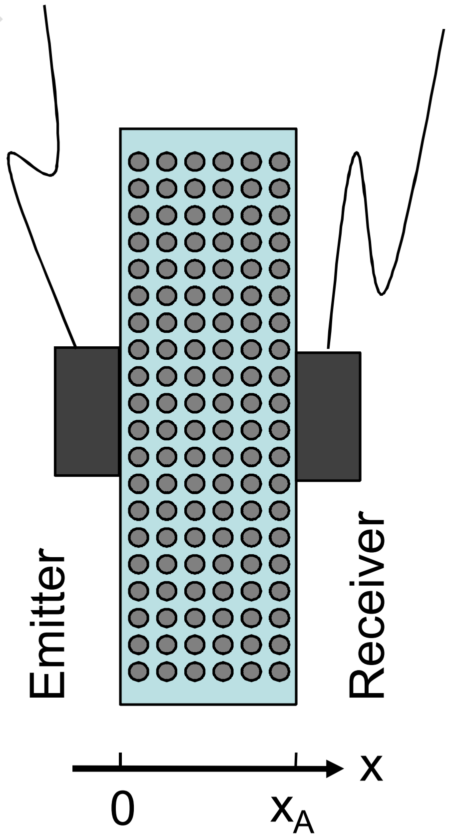
The shaded area represent the first absolute band gap : Hybridization gap for « longitudinal » bands and Bragg gap for « transverse » bands).

MULTEL [R. Sainidou, N. Stefanou, I.E. Psarobas, and A. Modinos, Comput. Phys. Commun. 166, 197 (2005)]

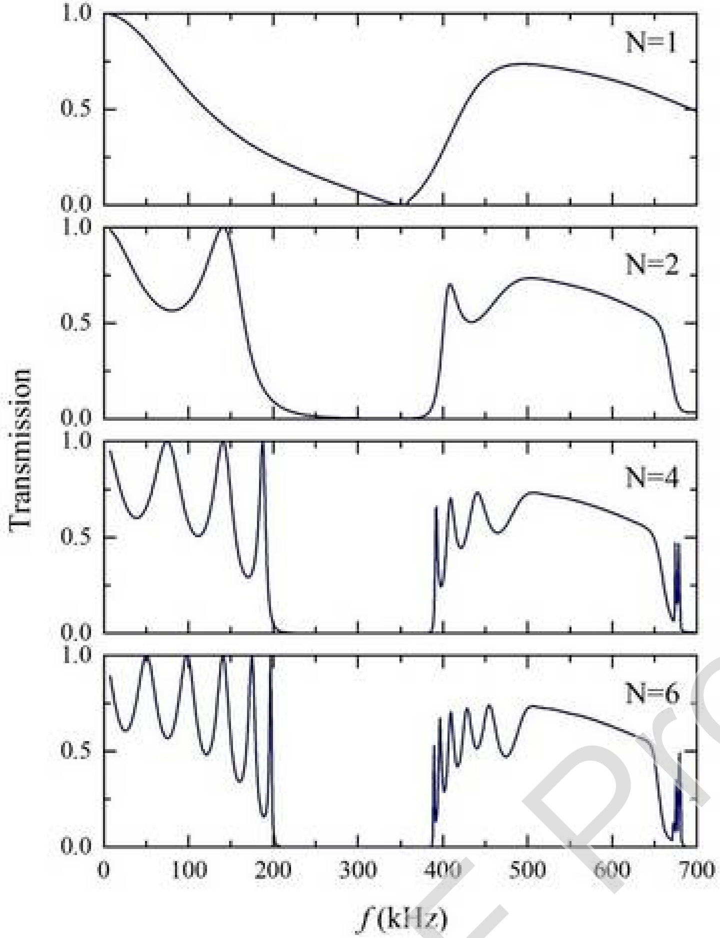
Square array of steel cylinders embedded in an epoxy matrix.

Transmission of a longitudinal (middle) and transverse (right) elastic wave incident normally on a six layers thick slab of the crystal whose band structure is also shown (left).

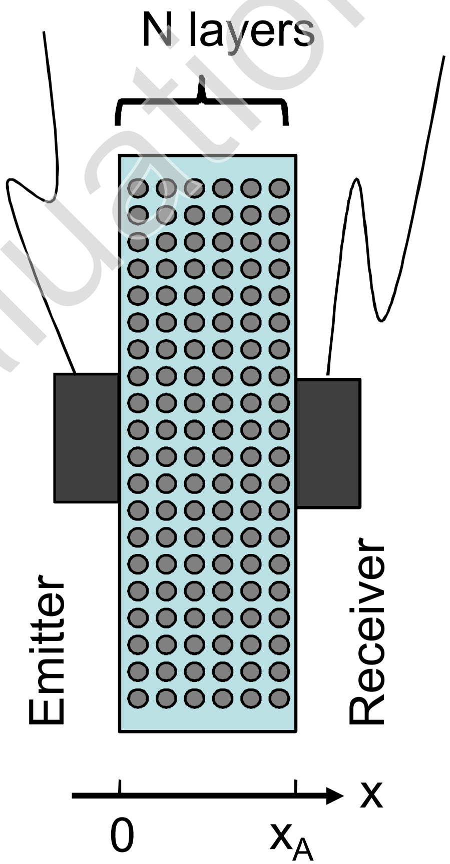




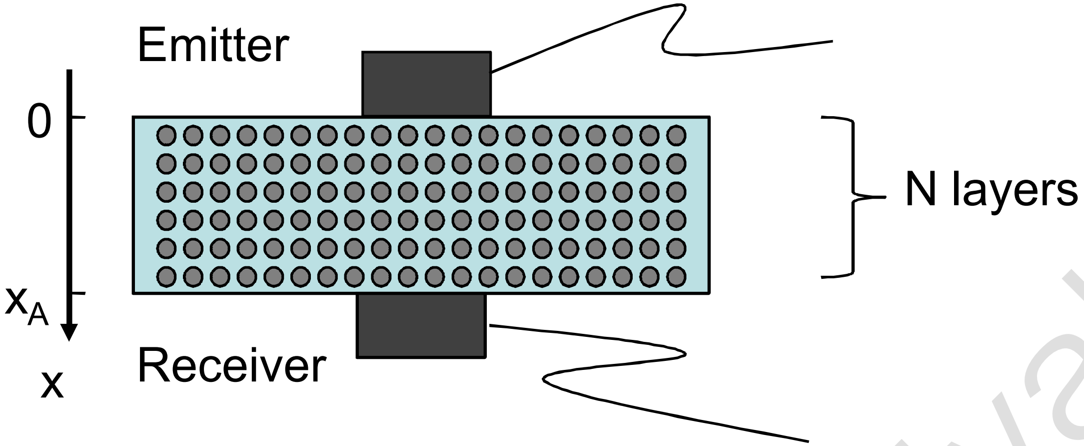
Square array of steel cylinders embedded in an epoxy matrix.

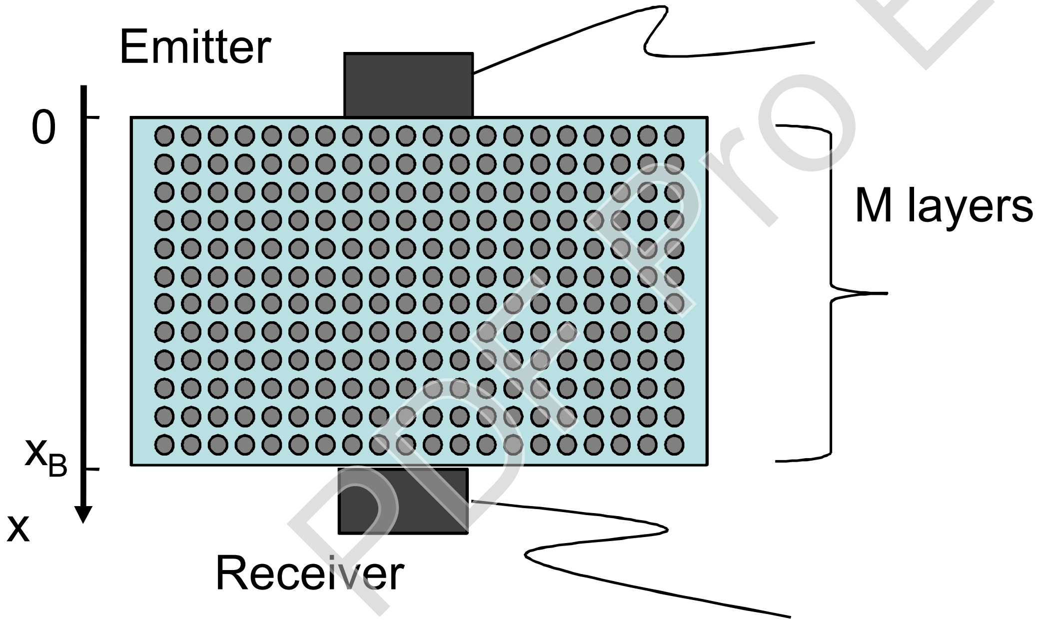


Transmission of a **longitudinal elastic wave** incident normally on a finite slab of the crystal consisting of *N* linear arrays of cylinders.



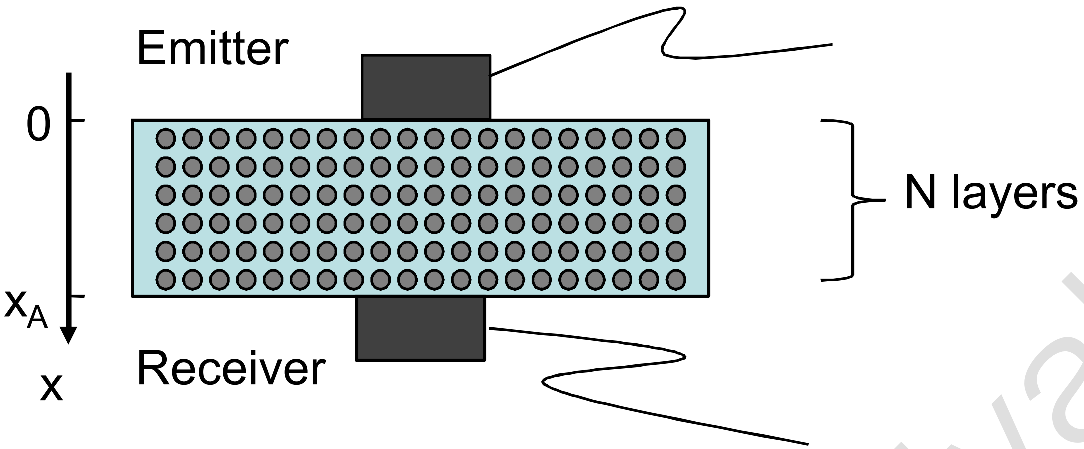
Square array of steel cylinders embedded in an epoxy matrix.



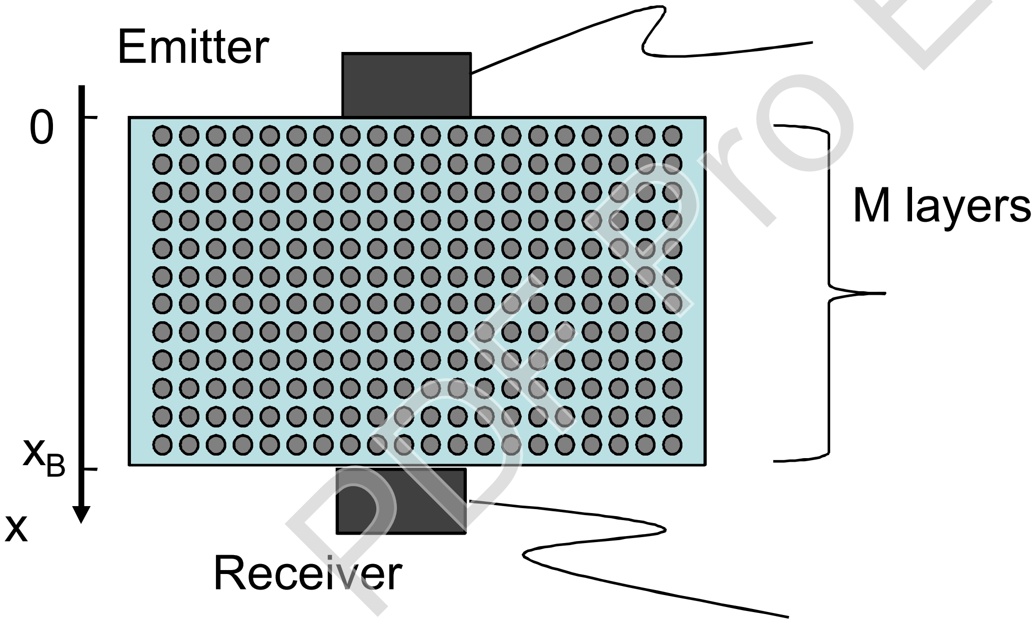


The experimental transmission through two different CP slabs of different thicknesses will be used to obtain the band structure of the CP.

Square array of steel cylinders embedded in an epoxy matrix.



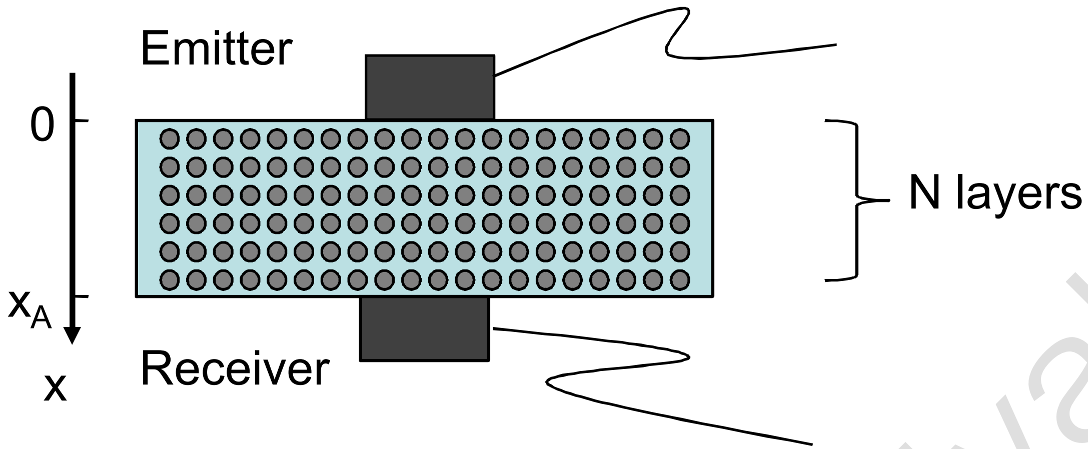
Fourier transform are performed on the transmitted signals through the PC with thicknesses respectivelly equal to x_A and x_B :



$$F_A(j\omega) = F(j\omega) \quad e^{jk_x' x_A} \; e^{-k_x'' x_A}$$

$$F_B(j\omega) = F(j\omega) \quad e^{jk_x' x_B} \; e^{-k_x'' x_B}$$

Square array of steel cylinders embedded in an epoxy matrix.



The ratio of the two previous FFT gives

$$Q = \frac{F_B(j\omega)}{F_A(j\omega)} = e^{jk_x'(x_B - x_A)}\ e^{-k_x''(x_B - x_A)}$$

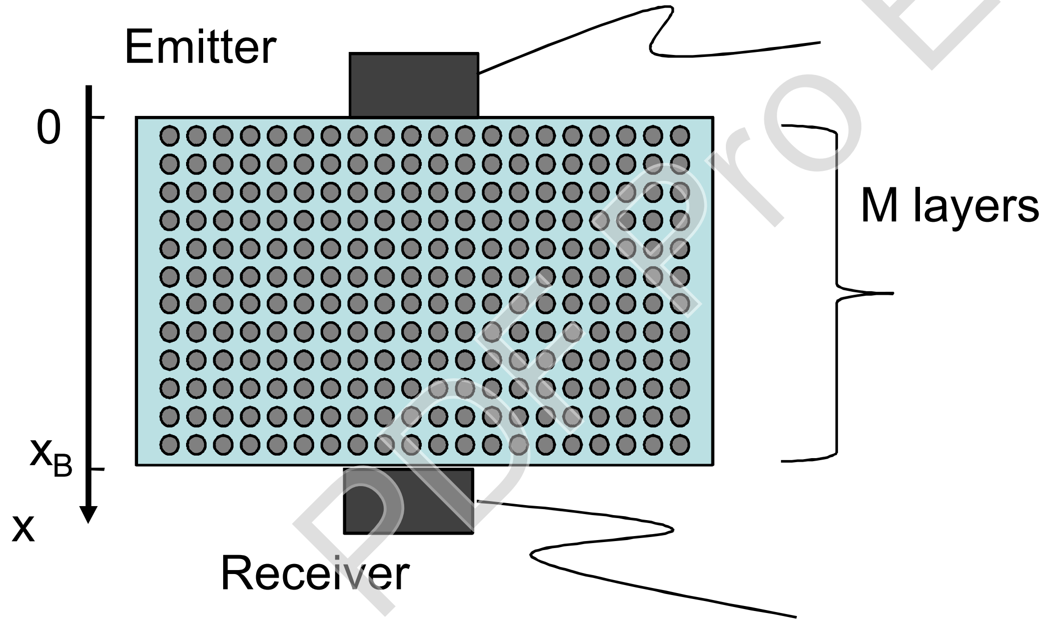
From which it is easy to deduced :

- The imaginary part of the wavenumber (attenuation)

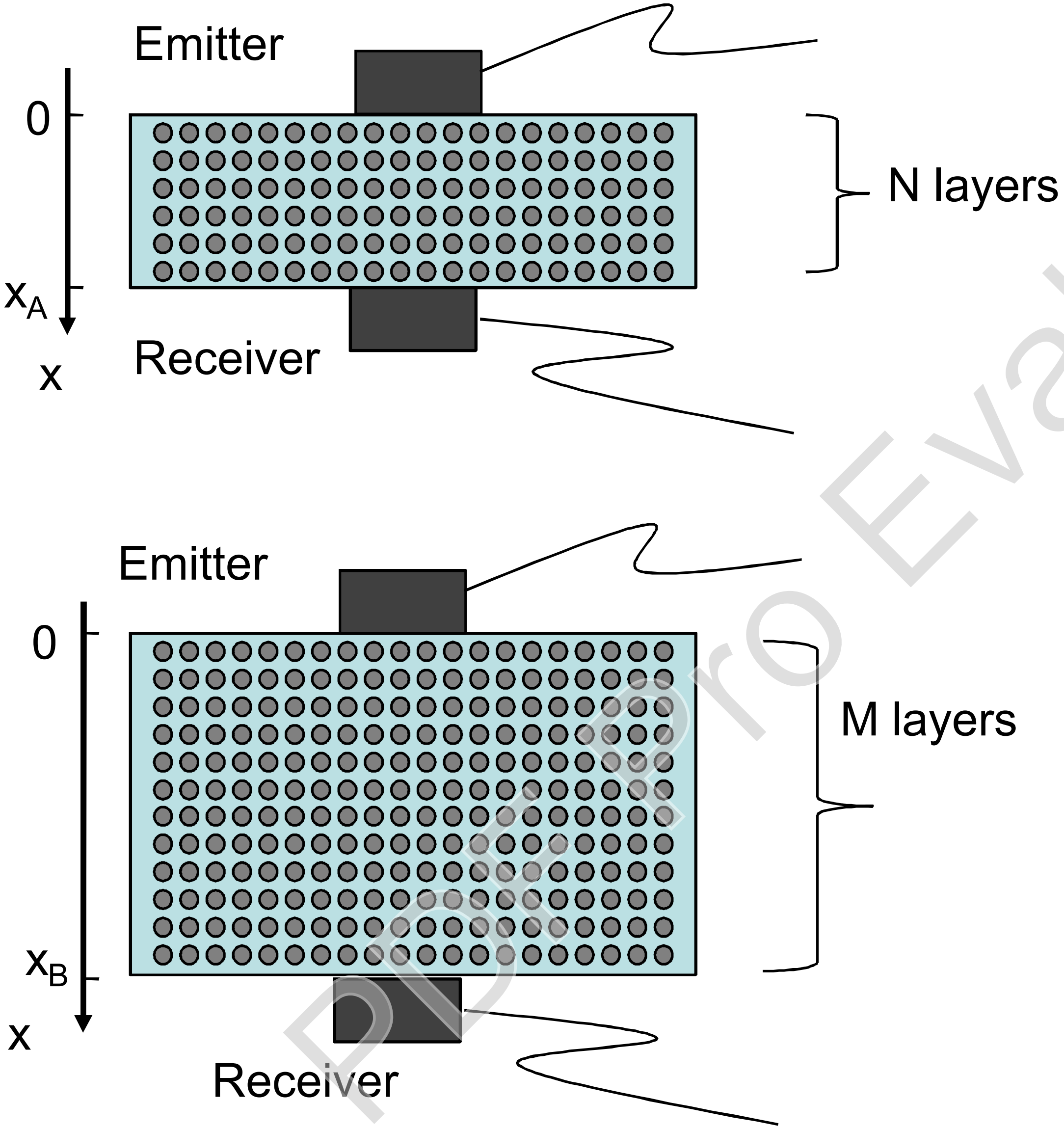
$$k_x'' = \frac{-ln|Q|}{(x_B - x_A)}$$

- The real part of the wavenumber (dispersion)

$$k_x' = \frac{\arg(Q)}{(x_B - x_A)}$$



Square array of steel cylinders embedded in an epoxy matrix.



EXPERIMENTS

Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

COLLABORATIONS

N. Swinteck, P.A. Deymier. *Department of Materials Science and Engineering, University of Arizona, Tucson, USA*

THE UNIVERSITY OF ARIZONA. TUCSON ARIZONA

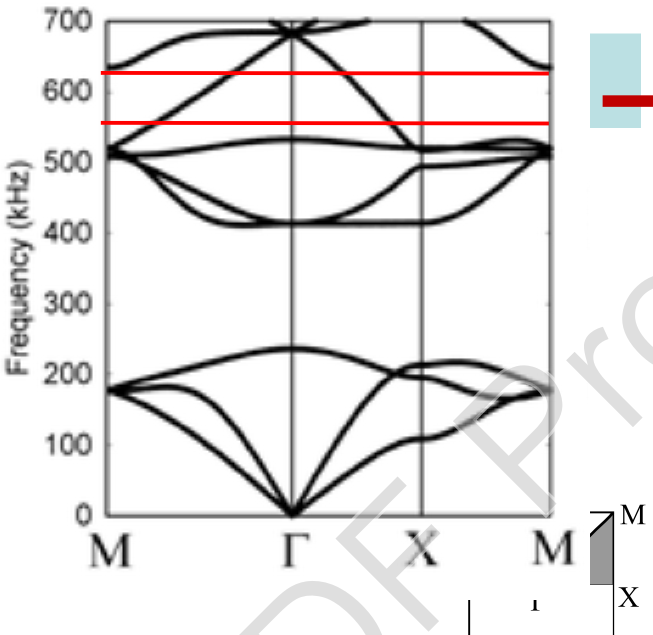
J. Vasseur. Institut d'Electronique, de Micro-électronique et de Nanotechnologie, UMR CNRS 8520.

iemn

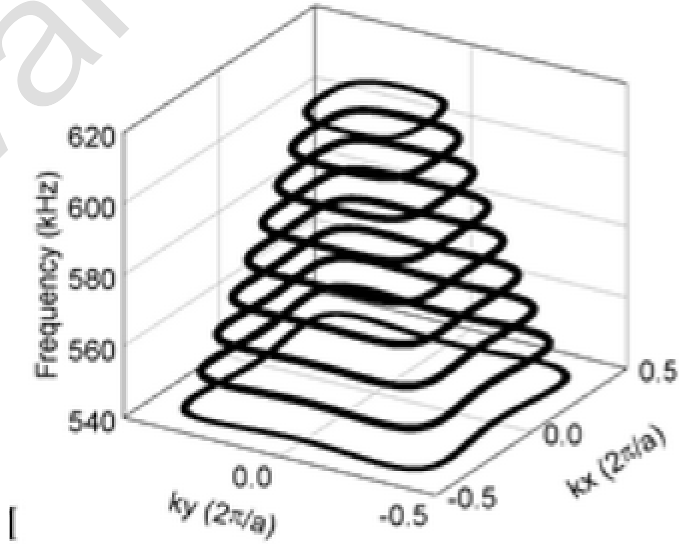
Square array of steel cylinders embedded in an epoxy matrix.

EFC($\omega = f(k_x,k_y)$) of square shape between 540 and 620 kHz

Longitudinal mode



Band structure



EFC

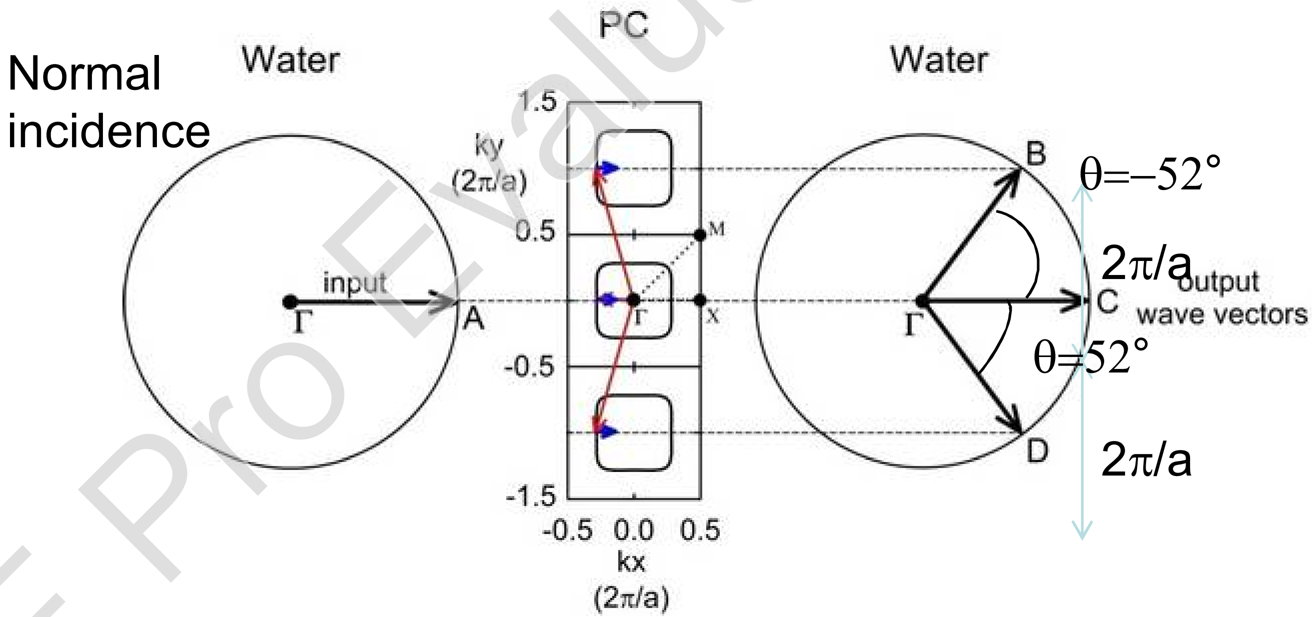
Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

Beam splitter

k-diagram at frequency F=590kHz

Conservation of the component of the k vector parallel to the interface between the entrance (resp. exit) medium and the input (resp. output) side of the phononic crystal



$|\mathbf{k}_{water}|=\Gamma A=\omega/c_{water}$

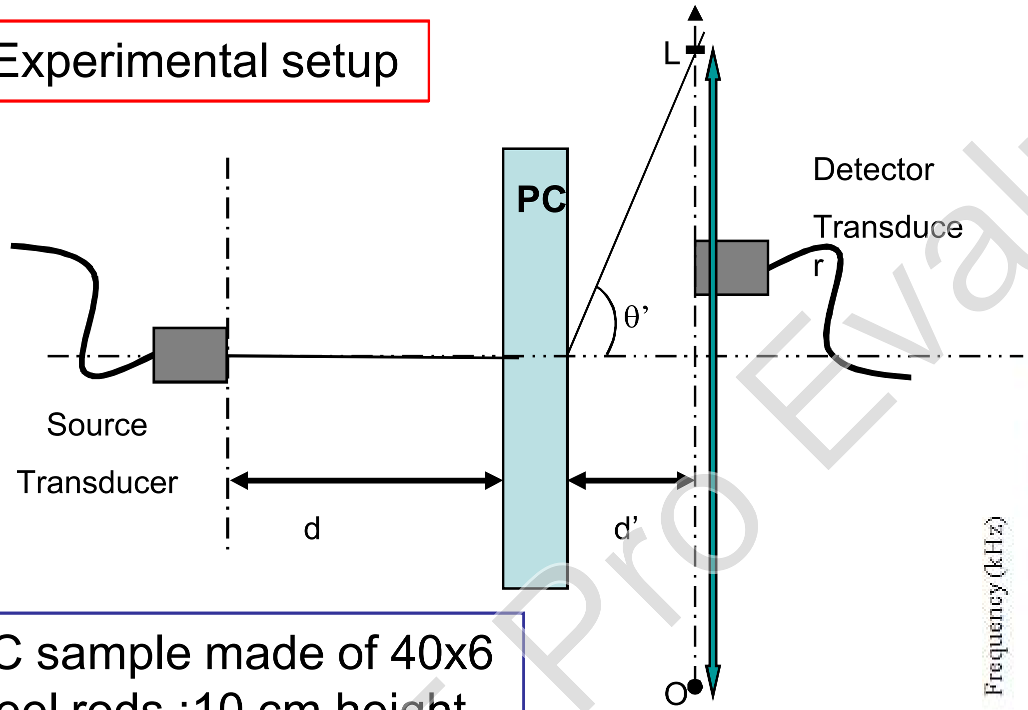
$|\mathbf{k}_{water}|=\Gamma B=\Gamma C=\Gamma D=\omega/c_{water}$

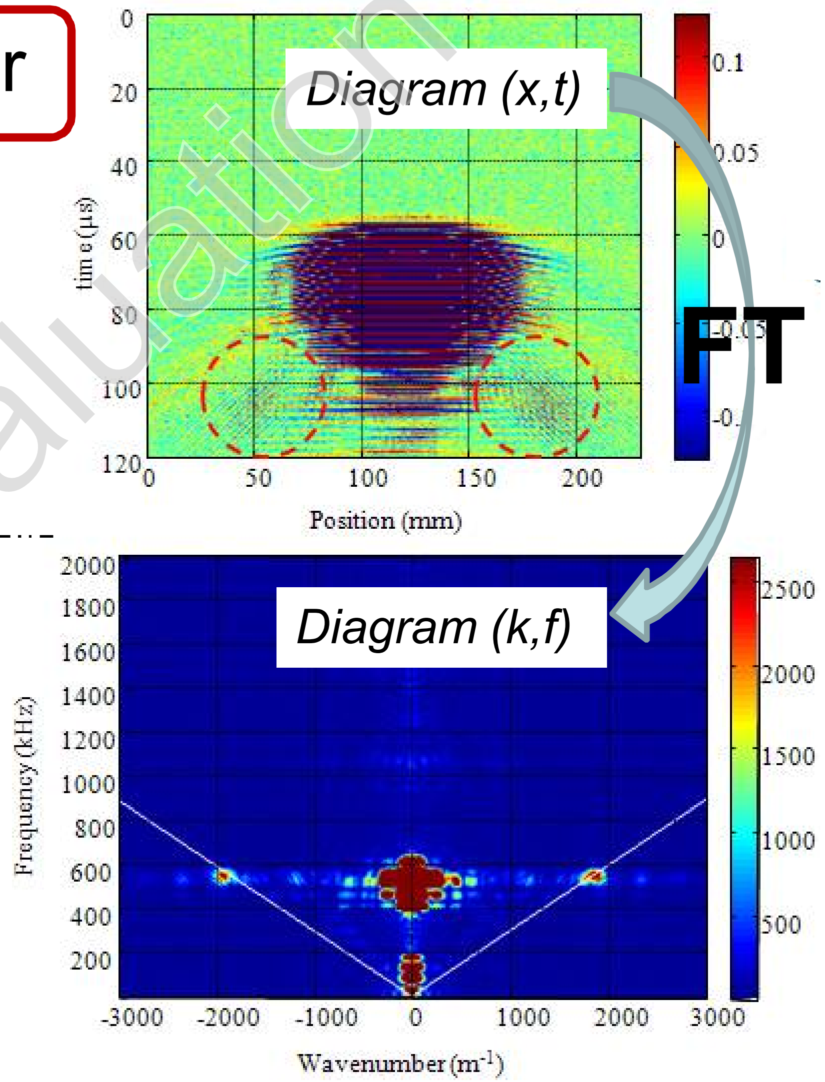
Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

Beam splitter

Experimental setup





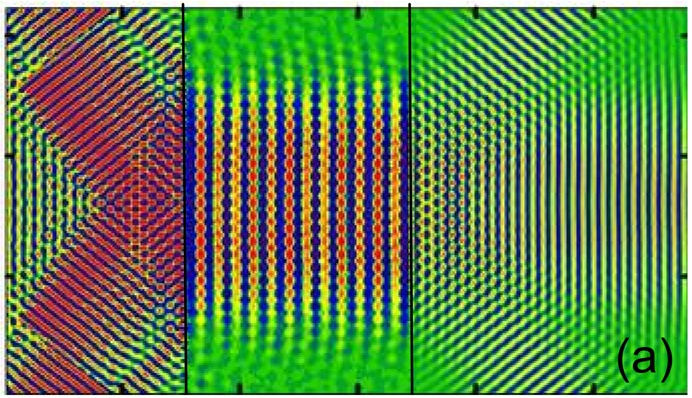
PC sample made of 40x6 steel rods ;10 cm height

3 waves exit the PC at 0° and at ±51°

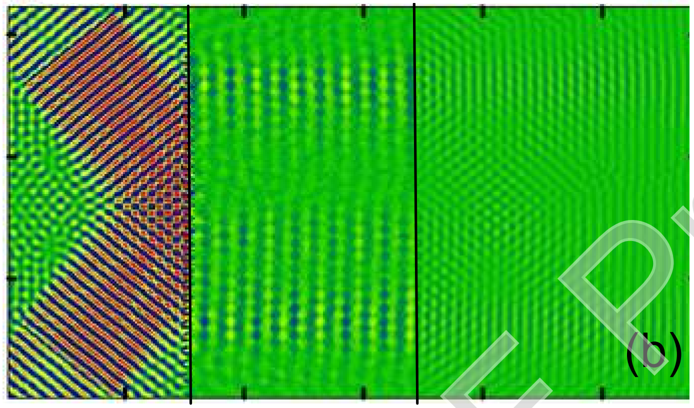
Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

Phase control device



Frequency = 590 kHz



Phase control device

FDTD pressure field calculation

Two acoustic waves (complementary angle inputs) in water impinge upon the PC surface at +52° and -52°.

(a) acoustic sources oscillate in-phase and excite identical Bloch modes in the PC k-space. Bloch wave amplitudes constructively interfere inside the PC and highly intense, collimated acoustic energy is observed inside the PC. On the backside of the PC, beam splitting is observed. The three exiting beams are very intense due to constructive wave interference.

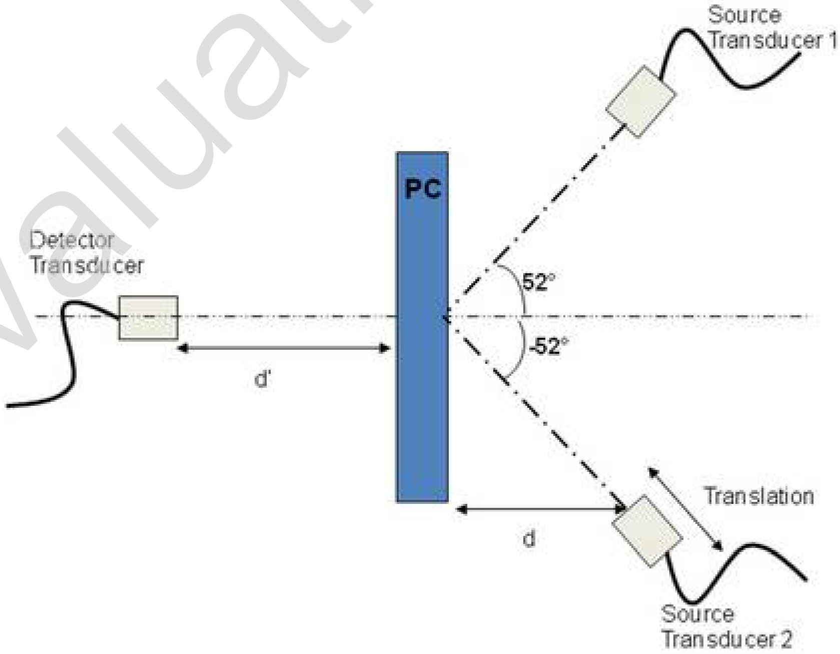
(b) acoustic sources oscillate π radians out-of-phase. Wave amplitudes destructively interfere inside the PC, resulting in a near-zero pressure field on the backside of the crystal.

Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

Phase control device

Experimental setup

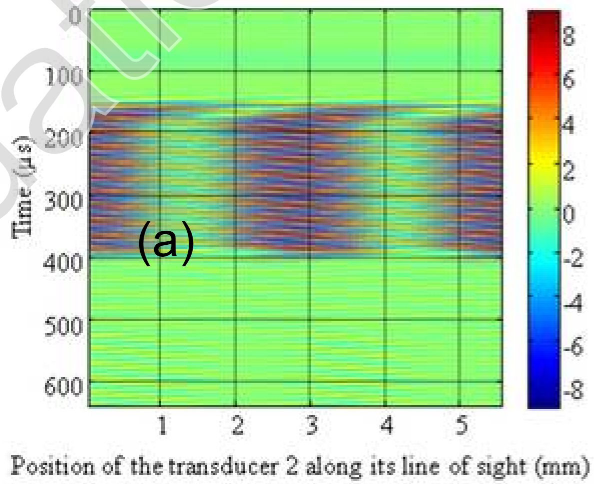


Square array of steel cylinders embedded in an epoxy matrix.

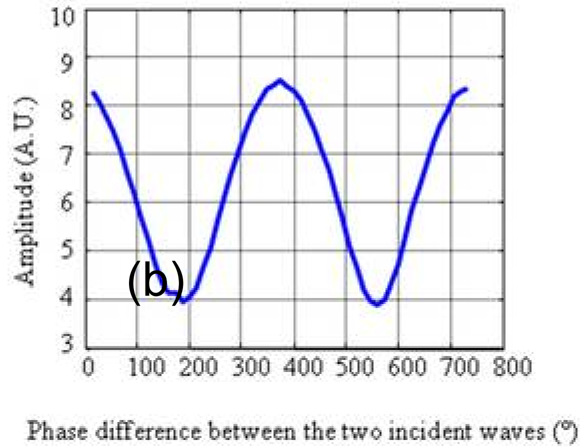
MULTI-FUNCTIONAL PHONONIC CRYSTAL

Phase control device

(a) Amplitude of the temporal response of a fixed detector transducer on the exit side of the PC subjected to two acoustic beams. The horizontal axis corresponds to the position of the second source along its line of sight;



(b) Response of the detection transducer as a function of the phase difference between the two incident beams. Maxima (resp. minima) occur for phase difference equal to an even (resp. odd) multiple of 180°= π rad.



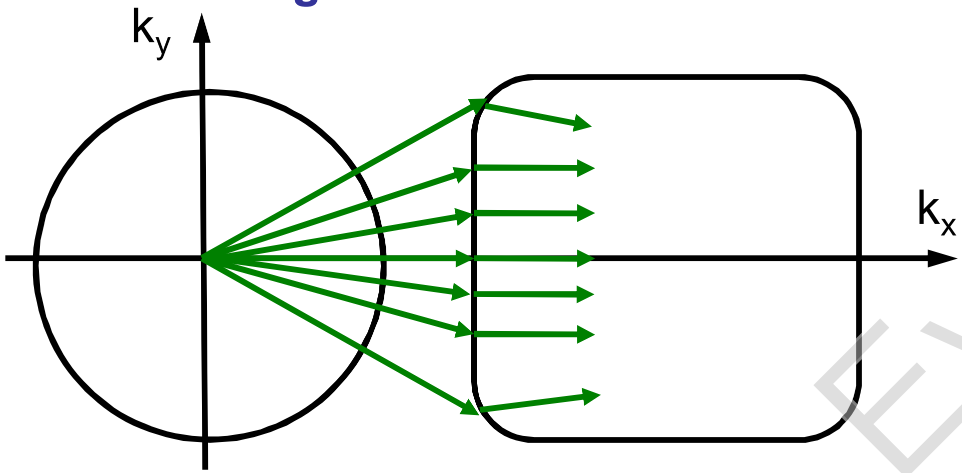
J.O. Vasseur *et al.*, PRB **86**, 134305 (2012)

Square array of steel cylinders embedded in an epoxy matrix.

MULTI-FUNCTIONAL PHONONIC CRYSTAL

Collimated beam

Angle de réfraction nul



• Exploitation de la forme carré des courbes équi-fréquences

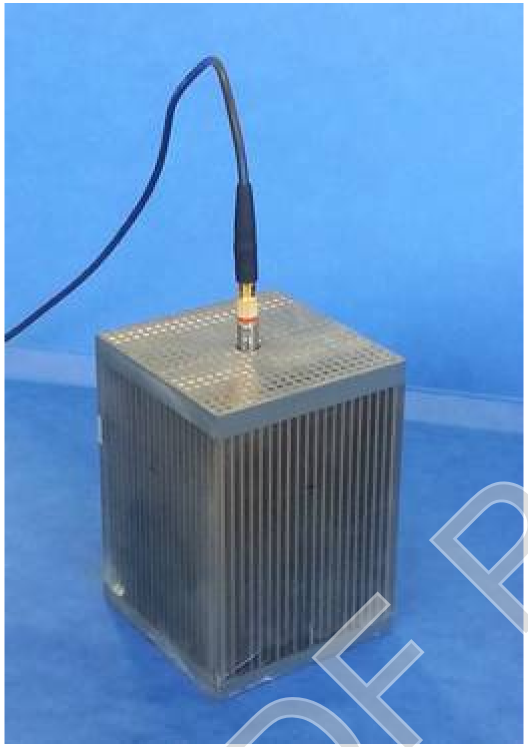
Contour équi-fréquence carré. La région plate du contour permet la collimation du faisceau.

Si on place la source dans le cristal phononique ?

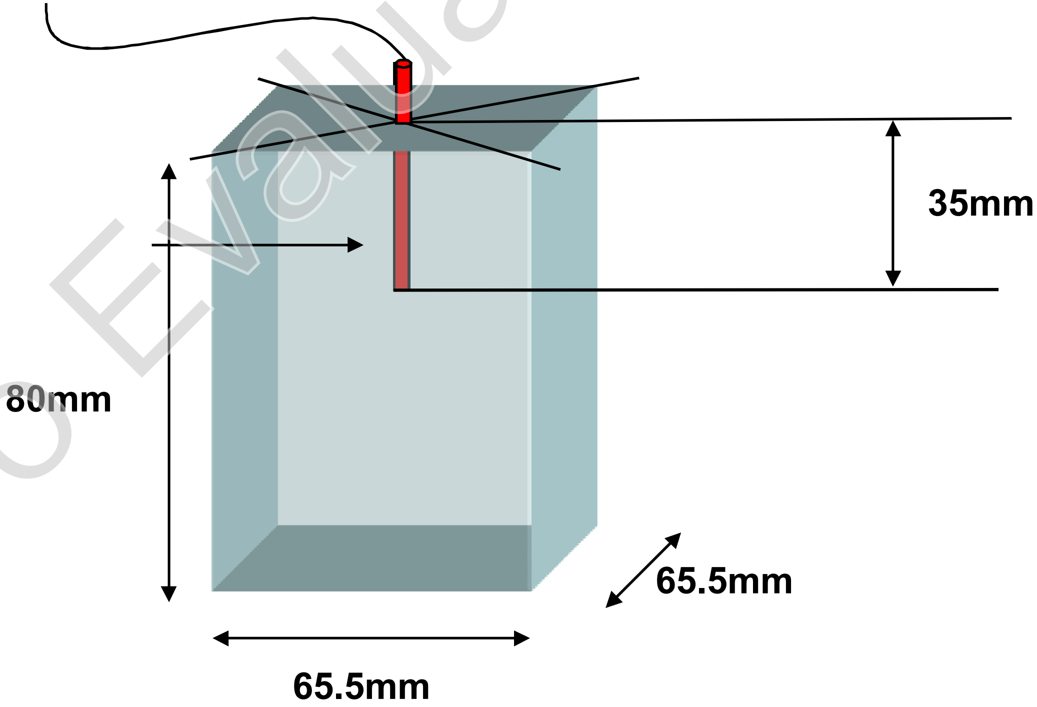
Square array of steel cylinders embedded in an epoxy matrix.

Présentation de l'échantillon

- **Le CP est constitué d'un réseau de 20 par 20 cylindres d'acier dans une matrice de résine epoxy**



Collimated beam

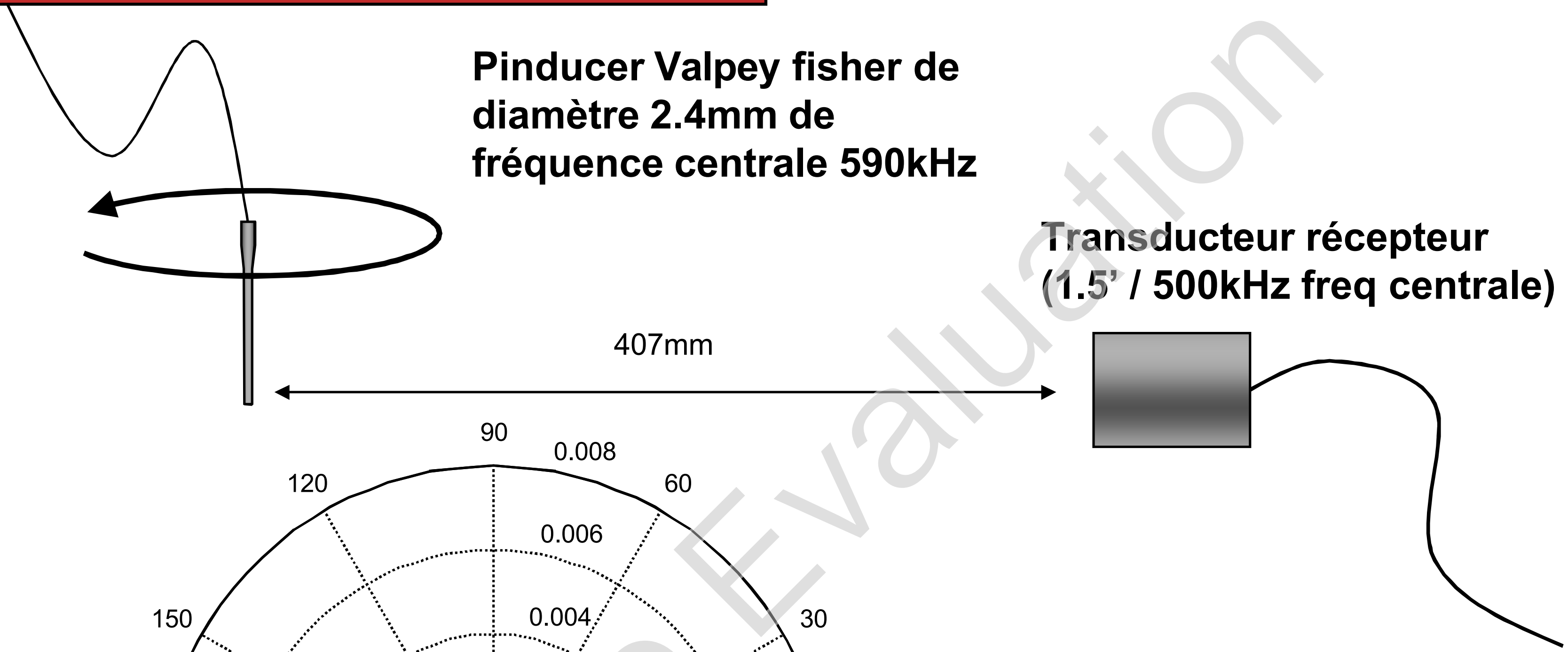


Square array of steel cylinders embedded in an epoxy matrix.

Pinducer characterization

Pinducer Valpey fisher de diamètre 2.4mm de fréquence centrale 590kHz

Transducteur récepteur (1.5' / 500kHz freq centrale)



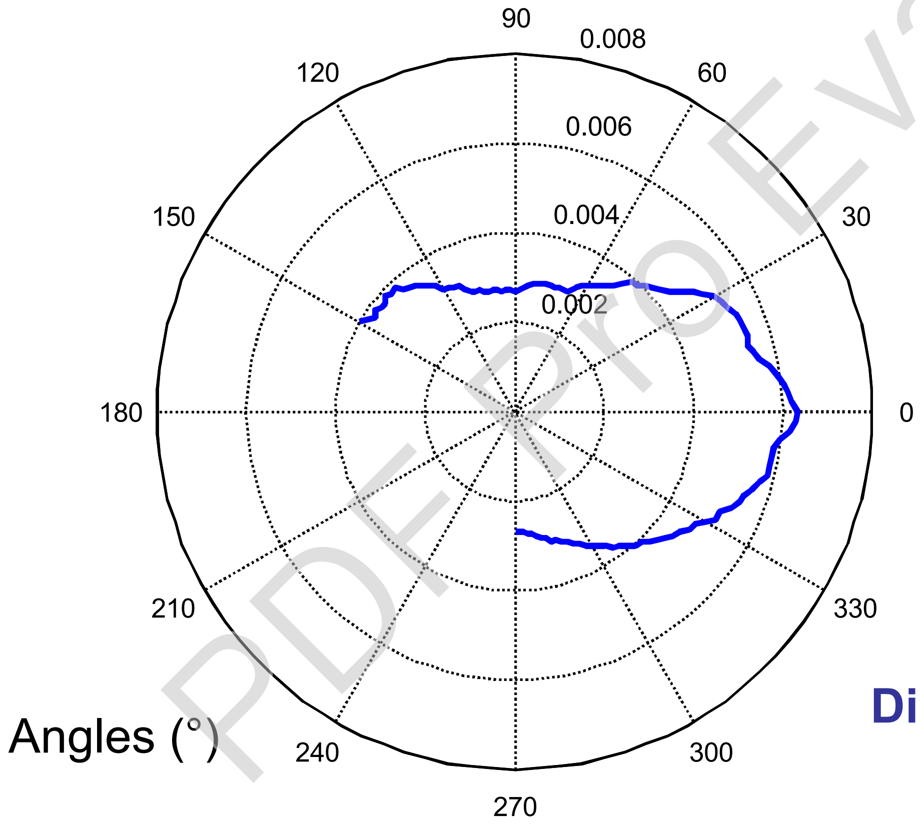


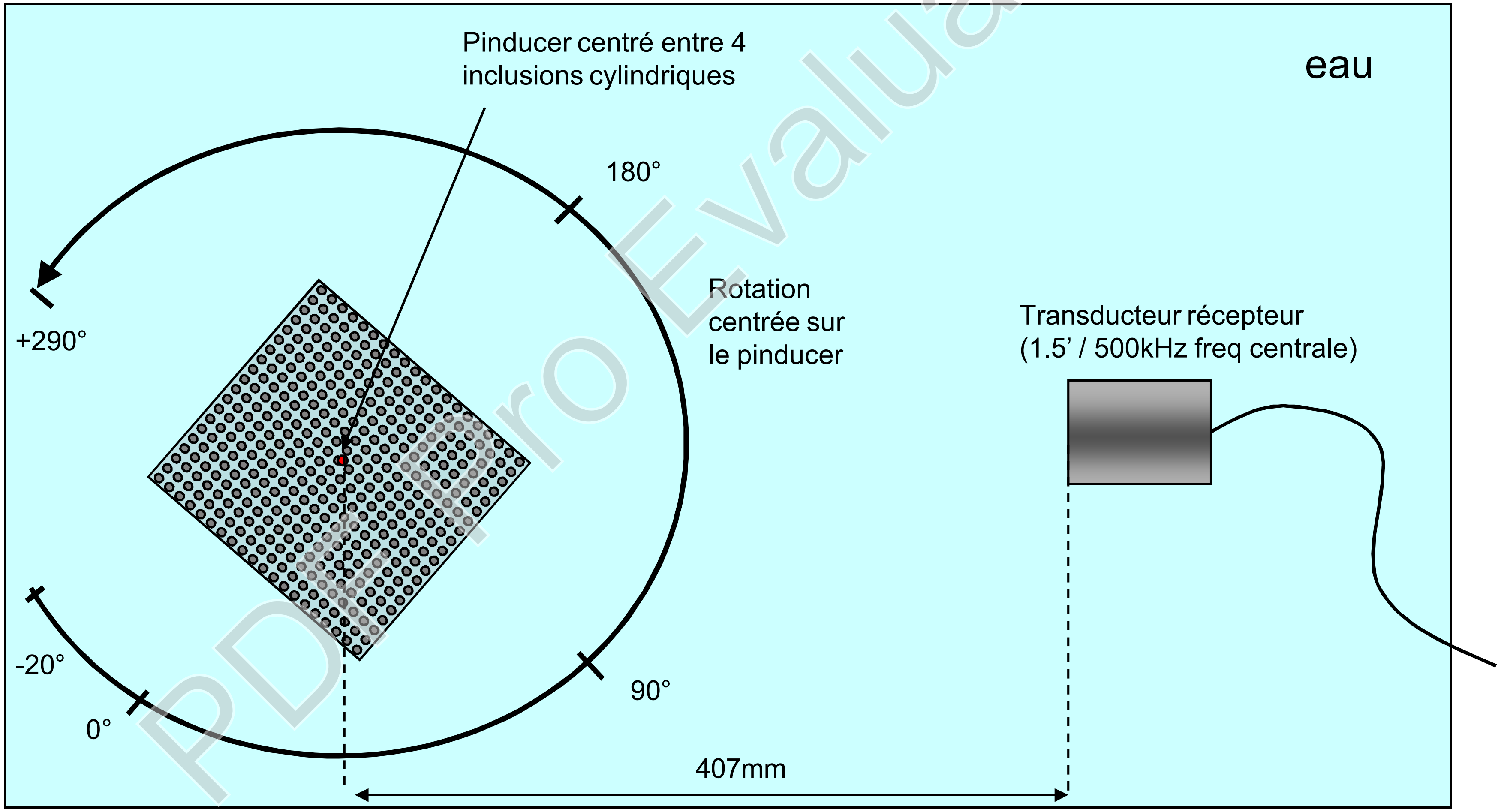
Diagramme de directivité à F=590kHz

Square array of steel cylinders embedded in an epoxy matrix.

Experimental set-up

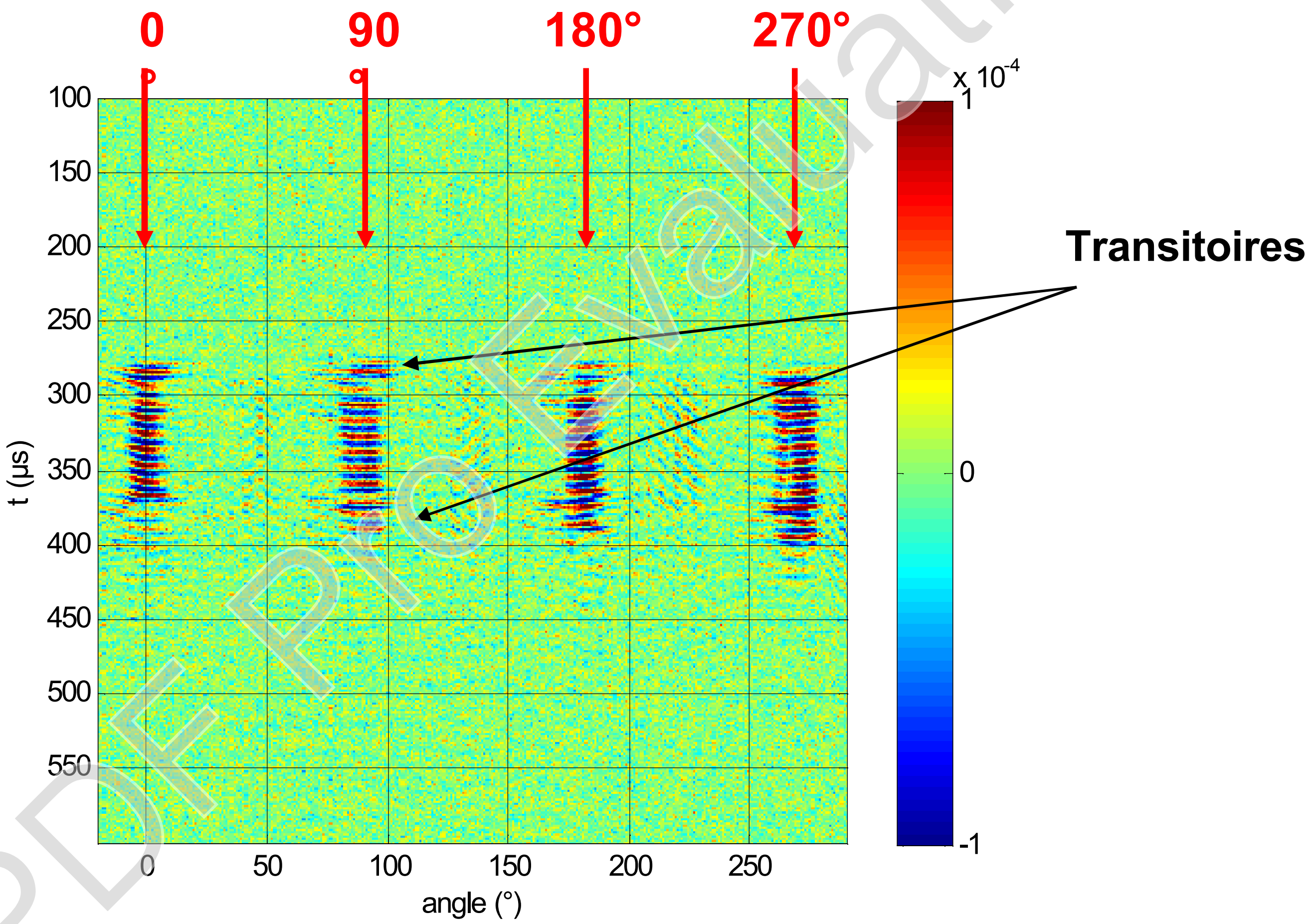
Le pinducer et le transducteur récepteur sont fixes, seul le CP tourne autour de son axe.

Signal d'excitation : train d'ondes de 50 périodes d'amplitude 50V et de fréquence 590kHz



Square array of steel cylinders embedded in an epoxy matrix.

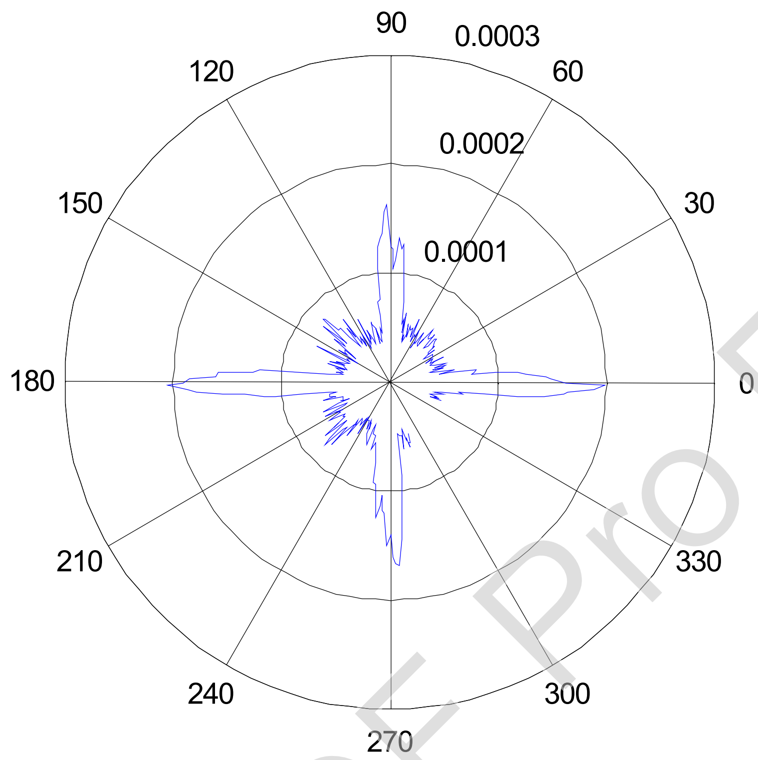
Signaux temporels en fonction de l'angle de rotation du CP



Square array of steel cylinders embedded in an epoxy matrix.

Diagramme de directivité

Amplitude en fonction de l’angle de rotation du CP
(dans le train d’onde (régime établi) entre 320 et 350µs)



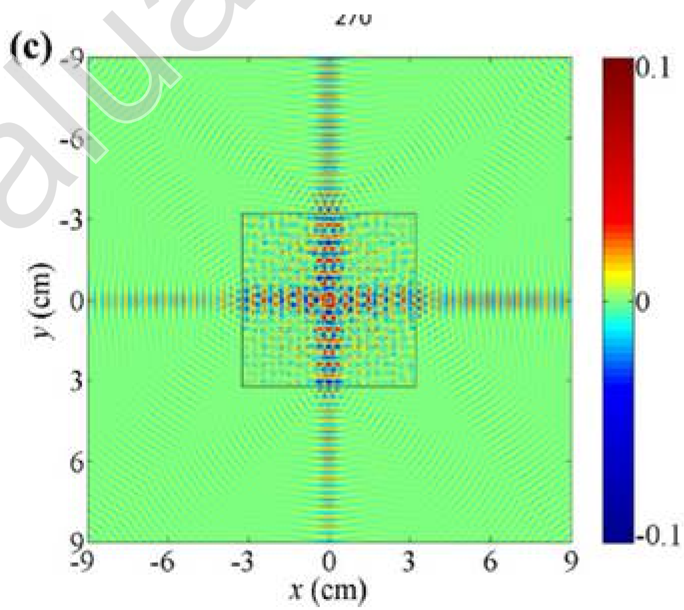


FIG. 4. Experimental maximum-amplitude (in arbitrary units) angular plot of signal received from the pinducer (a) immersed in water, (b) embedded in the PC block and immersed in water, and (c) pressure field (in arbitrary units) calculated using the FDTD method for case (b).

JOURNAL OF APPLIED PHYSICS 116, 214901 (2014)

Ultra-directional source of longitudinal acoustic waves based on a two-dimensional solid/solid phononic crystal

B. Morvan,[1] A. Tinel,[1] J. O. Vasseur,[2] R. Sainidou,[1] P. Rembert,[1] A.-C. Hladky-Hennion,[2] N. Swinteck,[3] and P. A. Deymier[3]
[1]*Laboratoire Ondes et Milieux Complexes, UMR CNRS 6294, Université du Havre, 75 rue Bellot, 76058 Le Havre, France*
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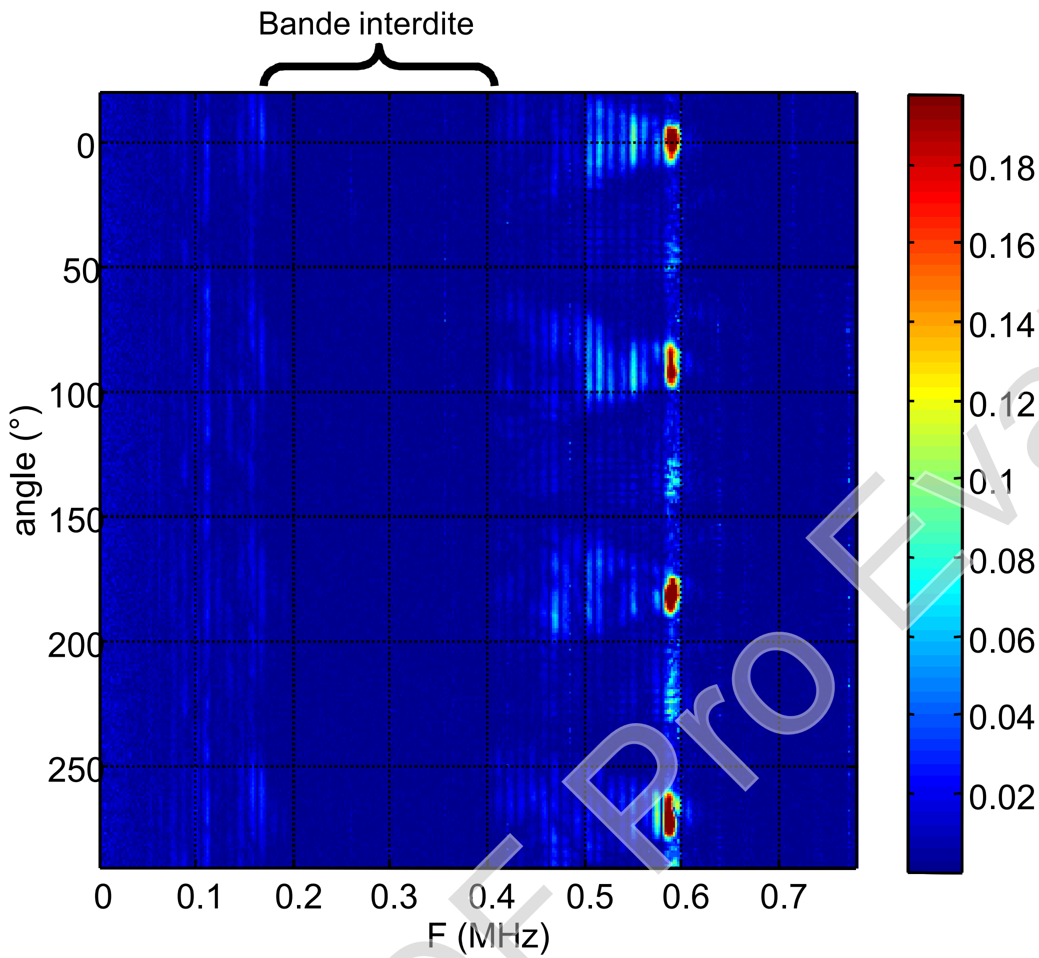
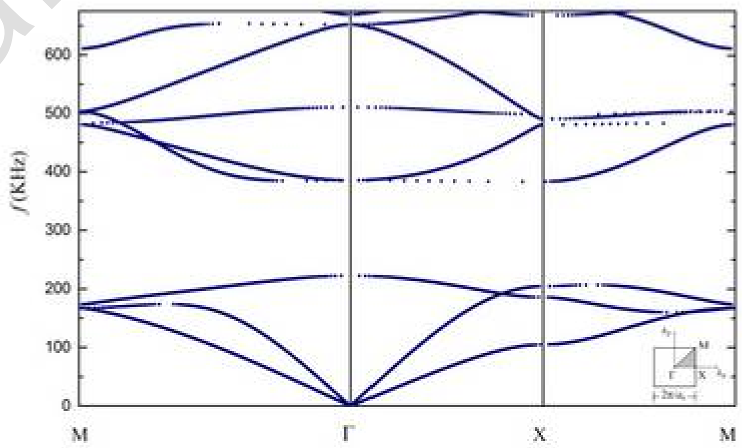
[3]*Department of Materials Science and Engineering, University of Arizona, Tucson, Arizona 85721, USA*

Simulation FDTD (N. Swinteck)

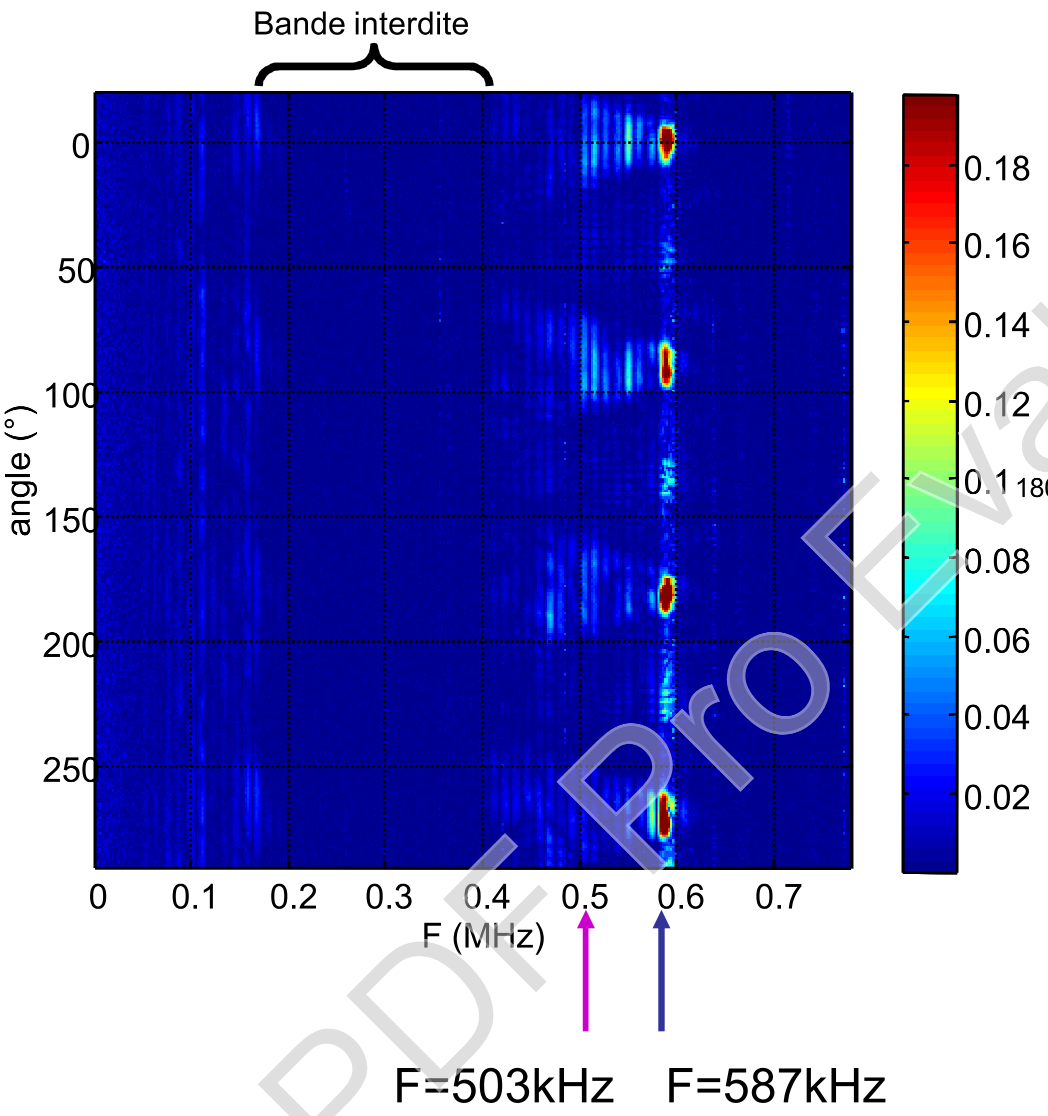
Spectres en fonction de l'angle de réception.

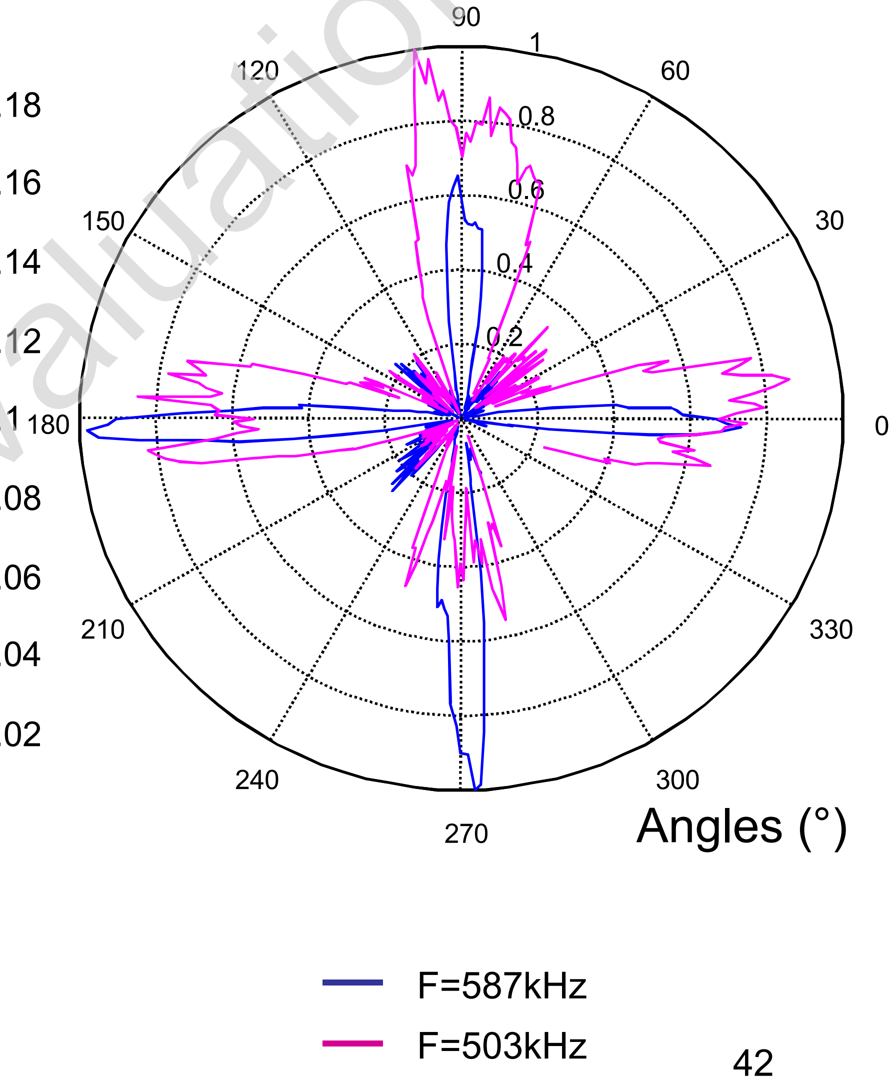


Structure de bandes du cristal phononique

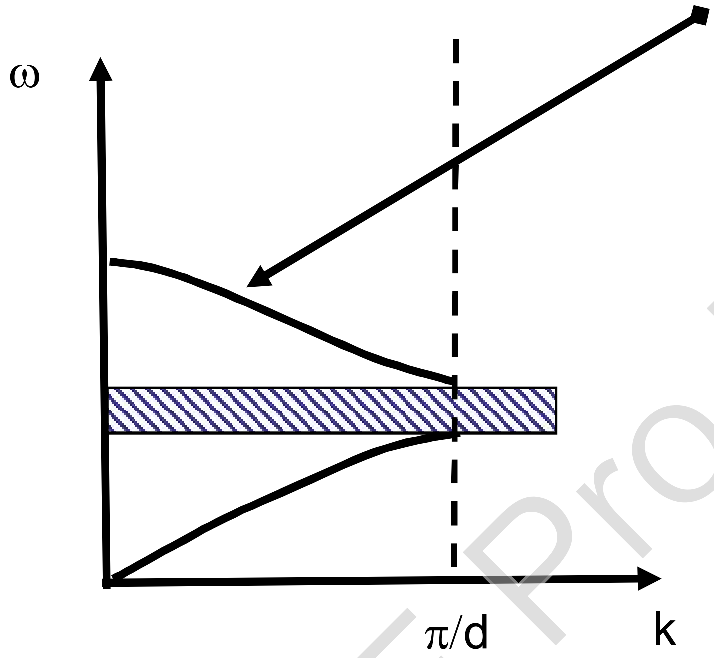


Spectres en fonction de l'angle de réception.





PART 2 : Experimental demonstration of the negative refraction in a solid PC



Wave with vg<0 et vφ>0

- Super-resolution lens
- Cloaking
- ….

Negative refraction

Point de départ de cette étude …..

Proposition de Veselago en 1968 dans son article :

“The electrodynamics of substances with simultaneously negative values of ε and μ”, Soviet Physics Uspekhi, vol. 10, No 4 (1968).

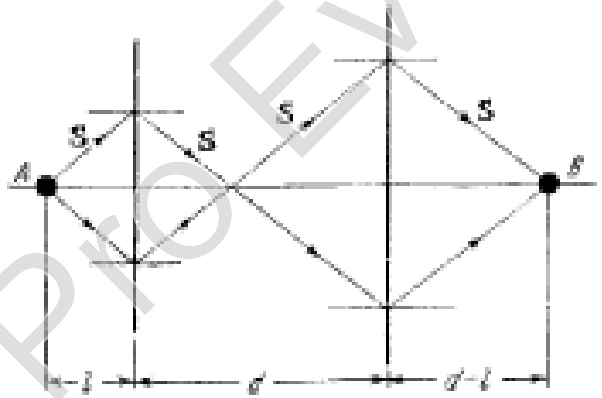
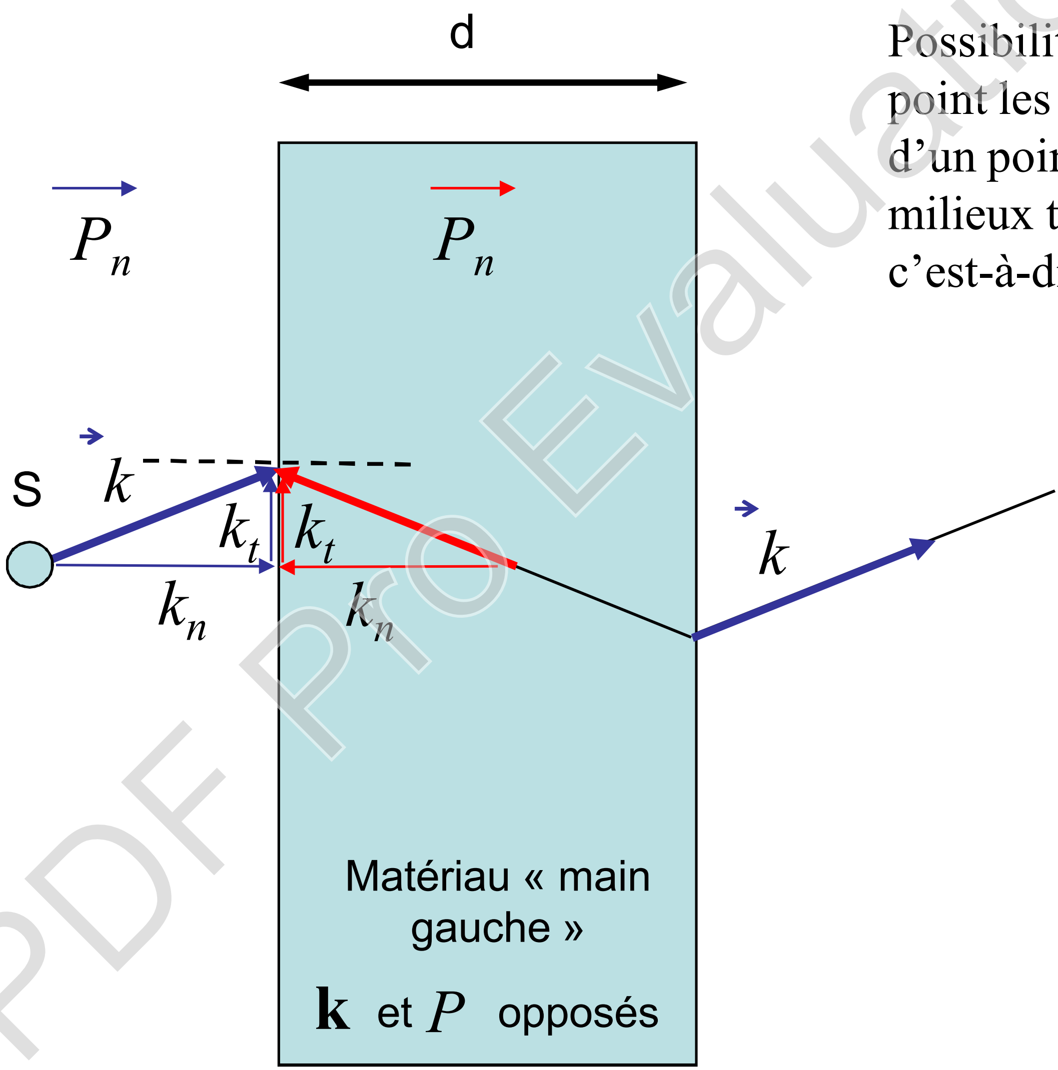


FIG. 4. Passage of rays of light through a plate of thickness d made of a left-handed substance. A – source of radiation; B – detector of radiation.

Negative refraction

Lentille super-résolution : principe

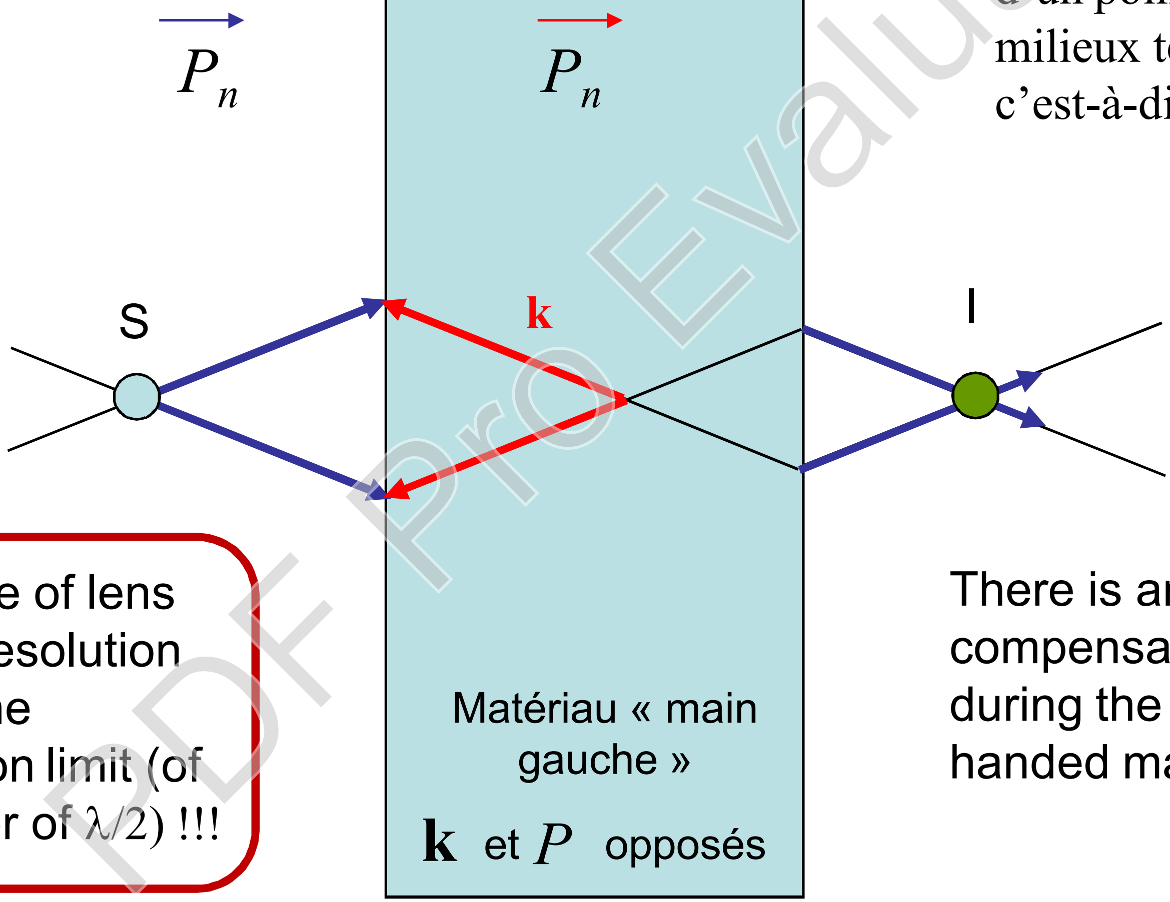


Possibilité de focaliser en un point les radiations issues d'un point source grâce à des milieux tels que e =-1 et m=-1 c'est-à-dire n=-1

Negative refraction

Lentille super-résolution : principe

Possibilité de focaliser en un point les radiations issues d'un point source grâce à des milieux tels que ε=-1 et μ=-1 c'est-à-dire n=-1

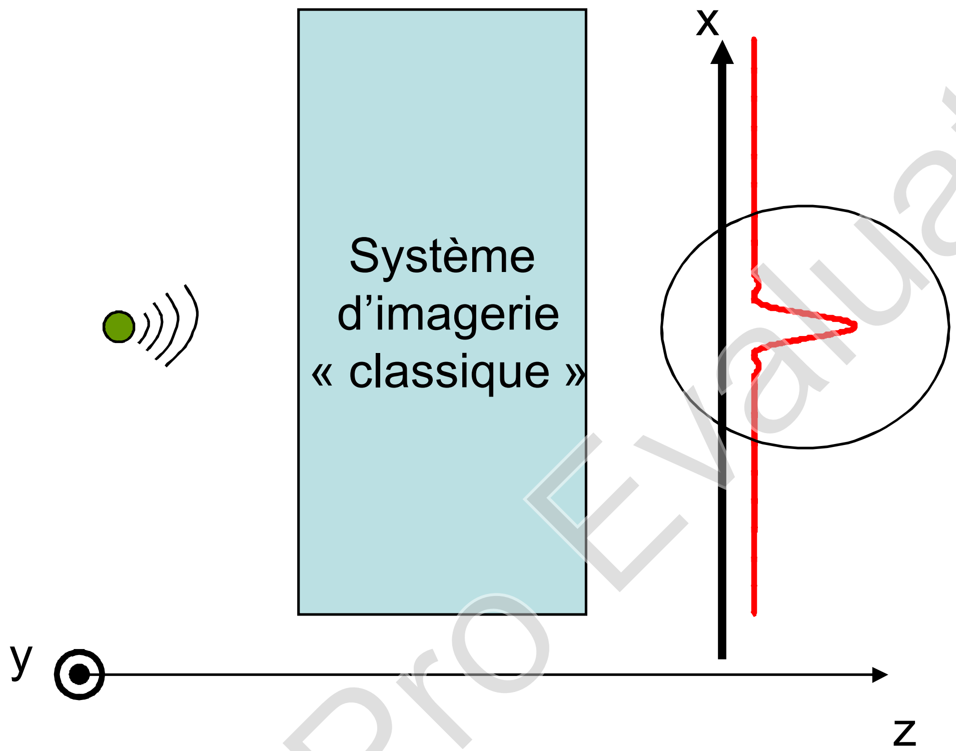


This type of lens allows resolution below the diffraction limit (of the order of $\lambda/2$) !!!

There is an exact compensation of the phase during the path in the left handed material

Negative refraction

Origin of the limit λ/2 in the resolution of the image



L'image de la source est formée à partir composantes propagatives du champ dans la direction z c'est-à-dire telles que :

$$k_z = \sqrt{\frac{\omega^2}{c^2} - k_x^2}$$

$$k_x^2 < \frac{\omega^2}{c^2}$$

Impose une limite $k_{max} = \omega / c$

et donc une limitation de la résolution spatiale du système d'imagerie :

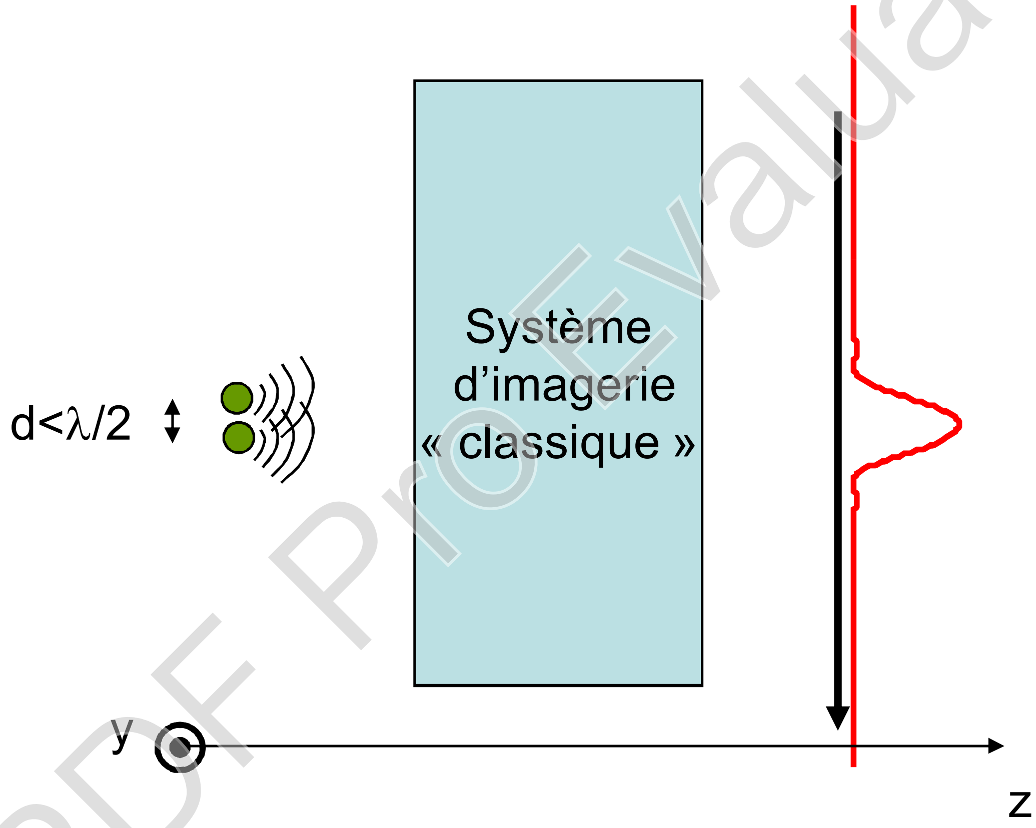
$$\Delta k_{max} . \Delta x = 2\pi \Rightarrow \Delta x \approx \lambda$$

Un point source donnera une « tache » image de largeur nécessairement supérieure à λ

Lentille super-résolution : principe

Limite « classique » de résolution d'image

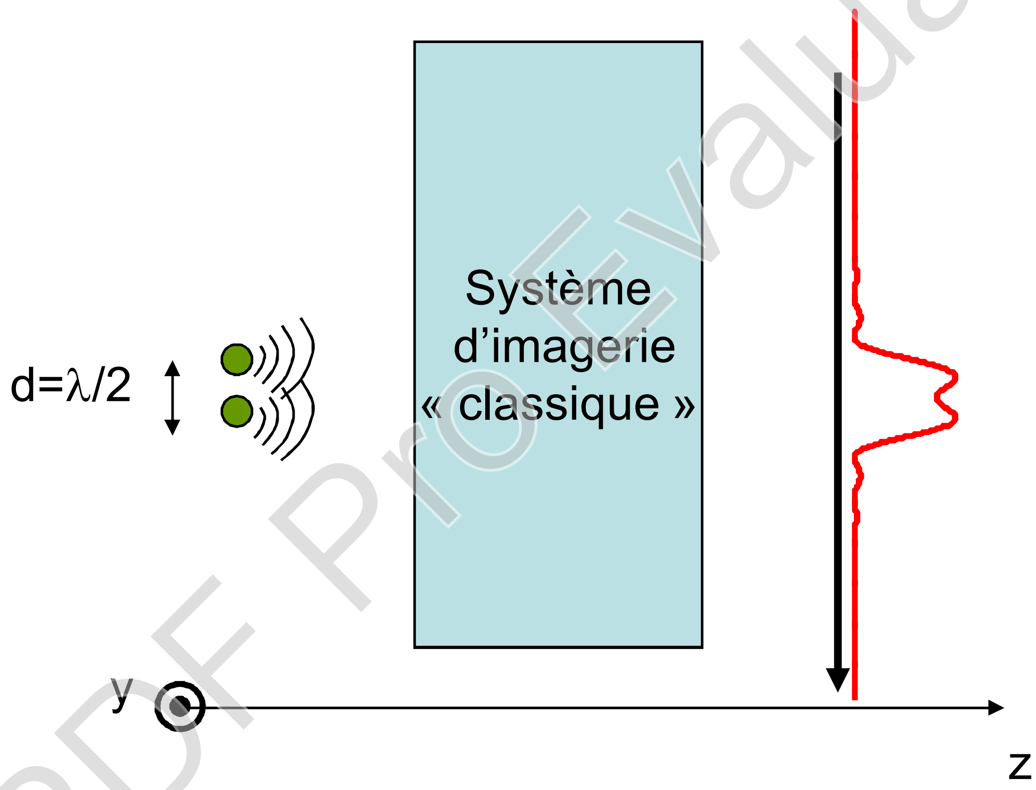
Critère de Rayleigh indique que la résolution D ne peut être meilleure que $\lambda/2$.



Lentille super-résolution : principe

Limite « classique » de résolution d'image

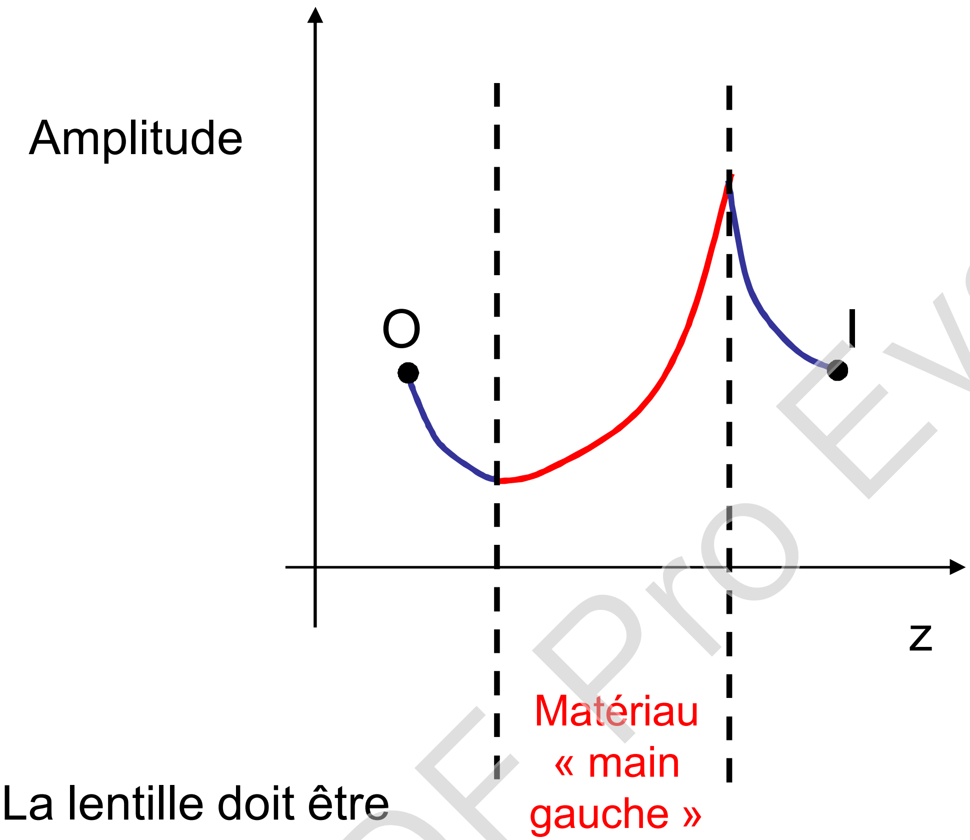
Critère de Rayleigh indique que la résolution D ne peut être meilleure que λ/2.



Negative refraction

Super resolution lens : principe

J. B. Pendry (Phys. Rev. Lett., 2000) reprend l'idée et montre que la lentille à réfraction négative permet de focaliser également les ondes « évanescentes » .



La lentille doit être dans le champ proche de la source

Compensation des phases mais aussi des amplitudes entre le point source et le point image

L'onde évanescente peut contribuer à la construction de l'image

Résolution meilleure que $\lambda/2$

Negative refraction

« Left handed » acoustic media ?

• L'équivalent acoustique du matériau « main gauche » proposé en électromagnétisme est obtenu pour $\rho_0 < 0$ et $\chi_S < 0$.

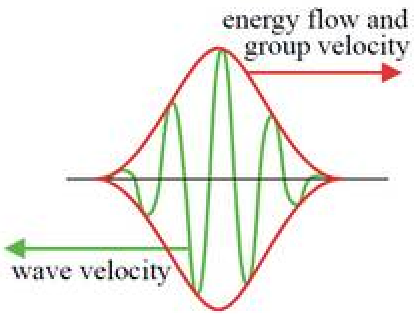
J. Li and C.T. Chan (Phys. Rev. E 70, 2004)

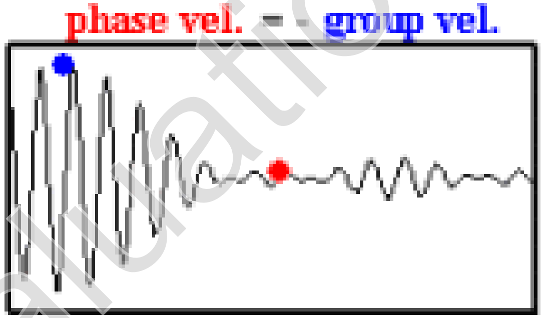
• Le vecteur d'onde et vecteur de Poynting pointent alors dans des directions opposées

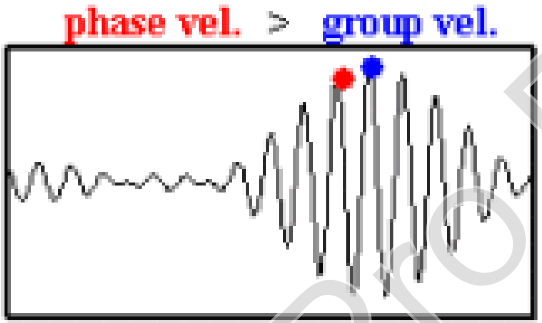
Pour une onde plane harmonique $e^{+j(kz-\omega t)}$

Équation d'Euler $\quad p.k = \rho_0 \omega v \longrightarrow pv.k = \rho_0 \omega |v|^2 < 0$

Negative refraction



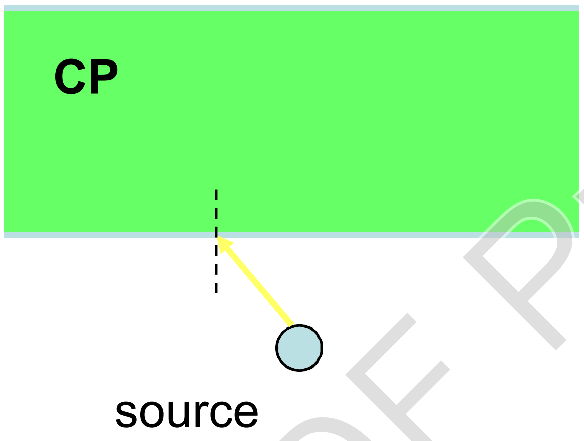


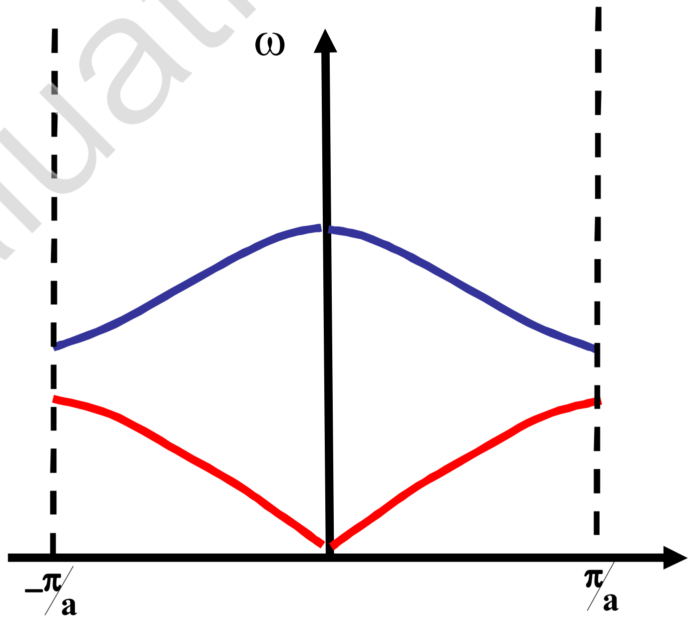


Une onde pour laquelle la vitesse de phase est opposée à la vitesse de groupe

Réfraction négative et lentille super résolution

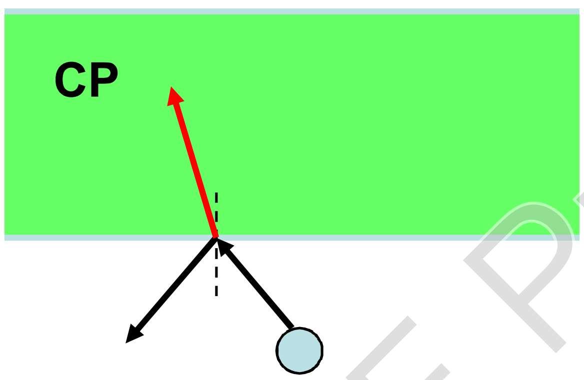
ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01

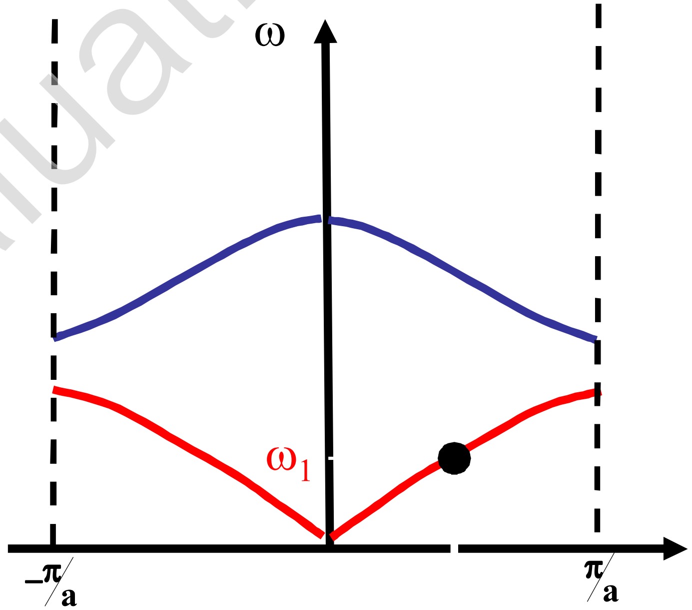




Réfraction négative et lentille super résolution

ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01



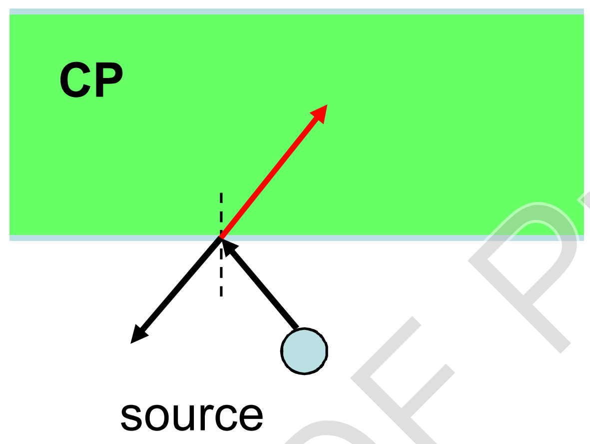


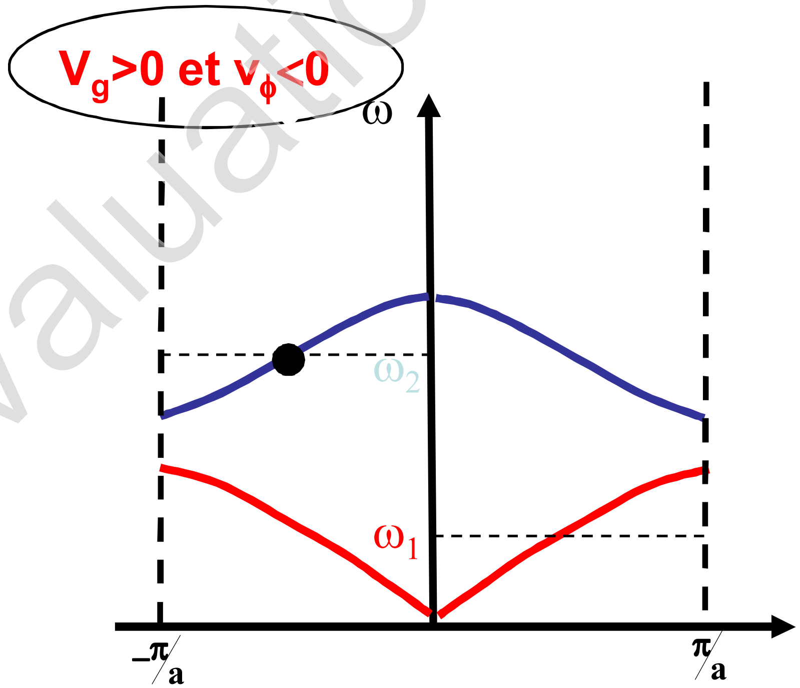
$V_g > 0$ et $v_\phi > 0$

Réfraction négative et lentille super résolution

ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01

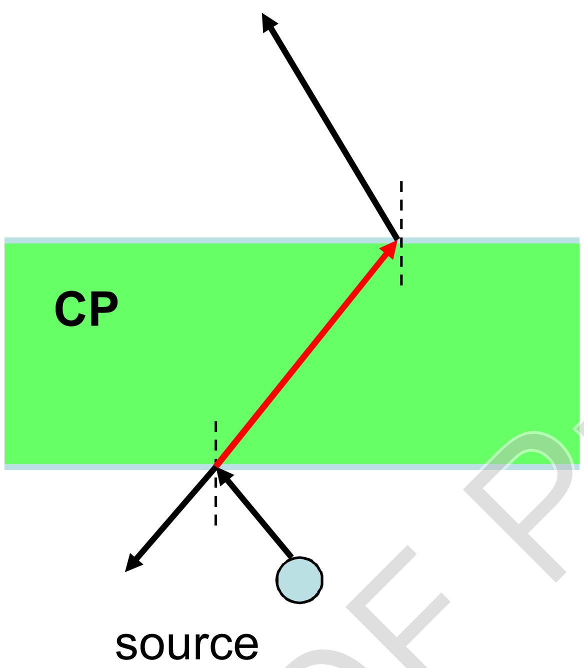
- Ondes à vitesses de groupe et de phase opposées : conséquence sur les lois de la réfraction.

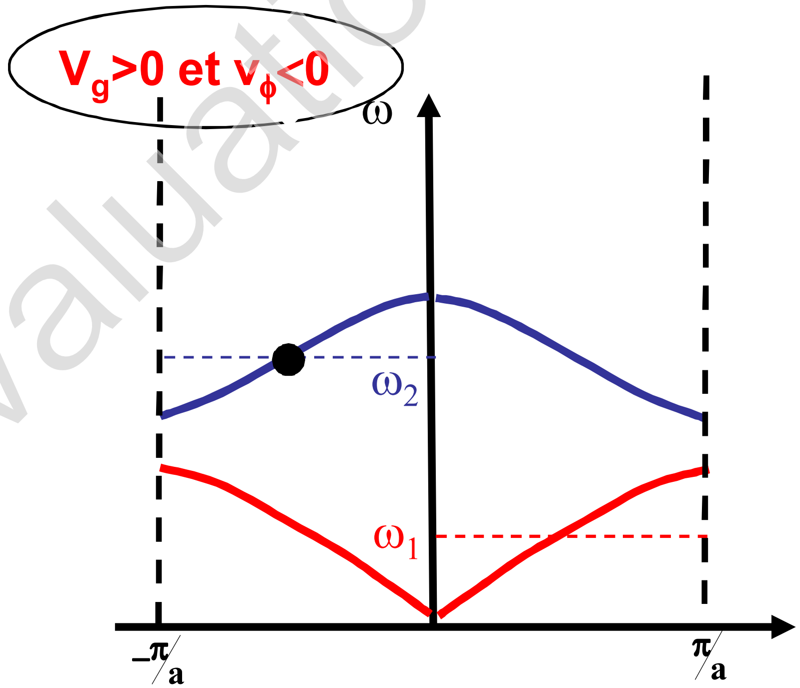




Réfraction négative et lentille super résolution

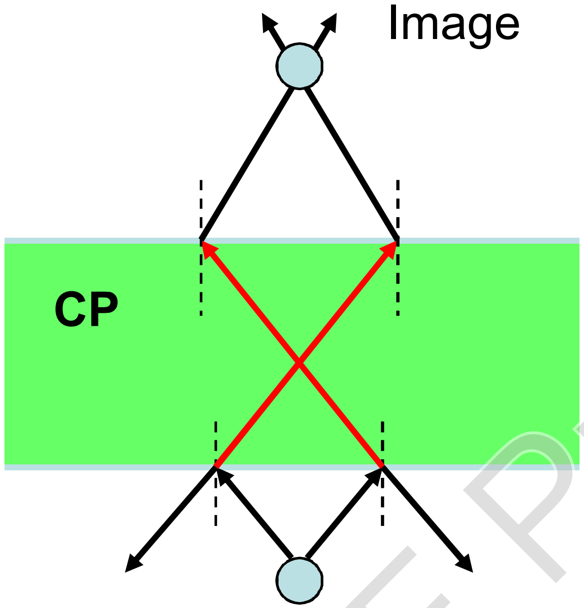
ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01

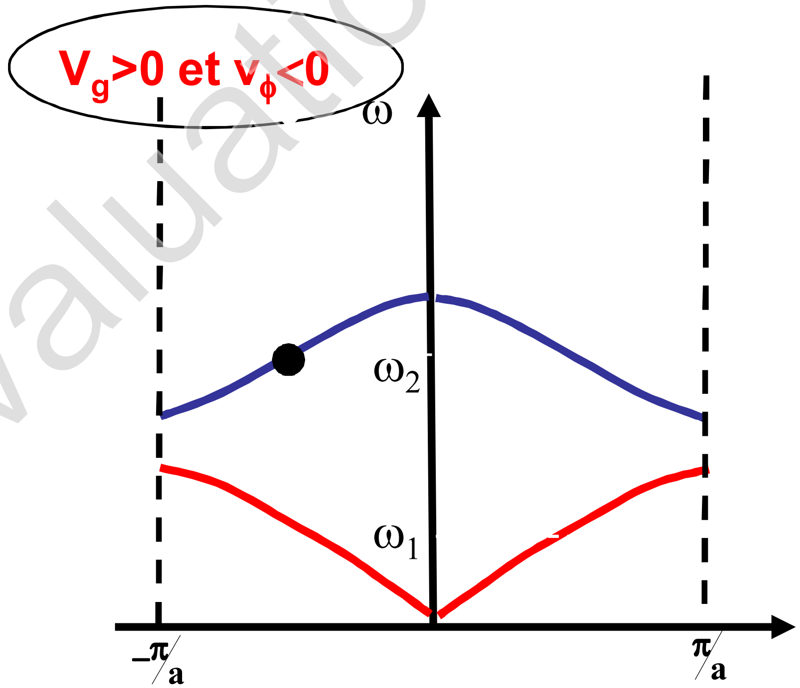




Réfraction négative et lentille super résolution

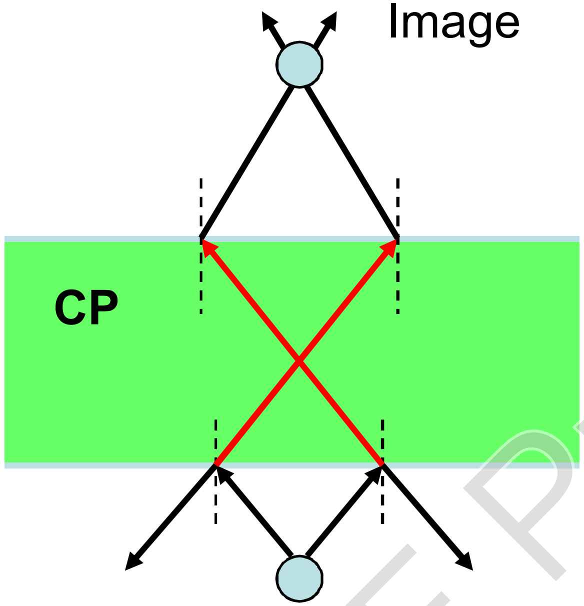
ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01





Réfraction négative et lentille super résolution

ANR « SUPREME » : SUPerlentille à REfraction négative à base de MEtamatériaux et cristaux phononiques, ANR-08-BLAN-0101-01



Ce type de lentille autorise des résolutions inférieures à la limite de diffraction (de l'ordre de $\lambda/2$) !!!

PHYSICAL REVIEW B 77, 014301 (2008)

Negative refraction and focusing of ultrasound in two-dimensional phononic crystals

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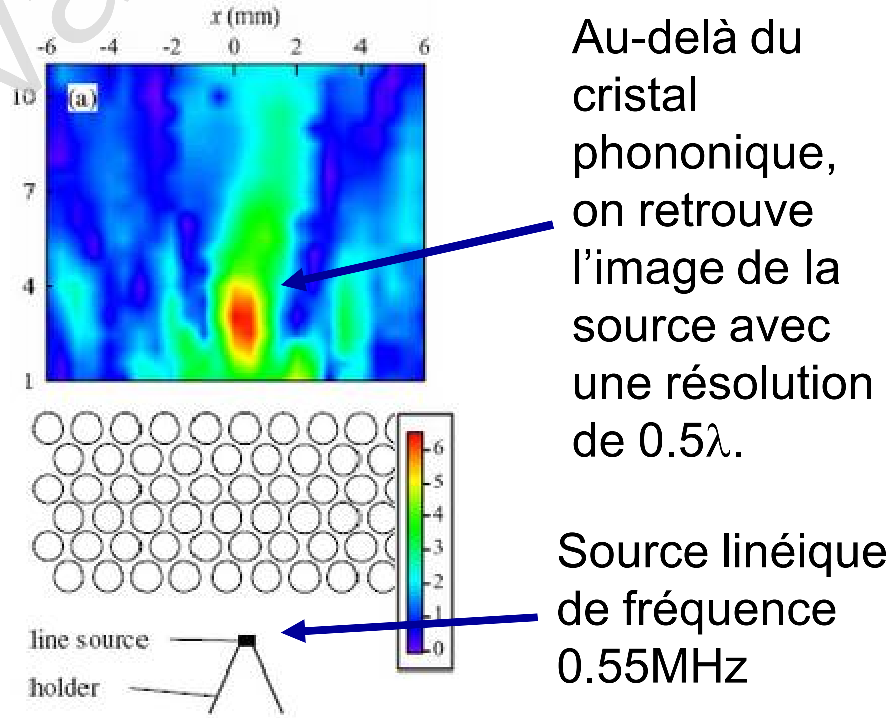
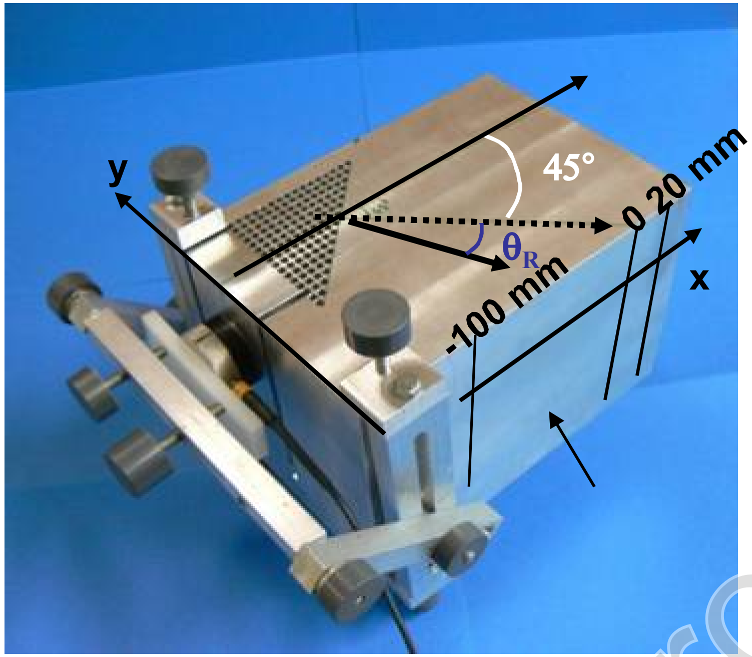
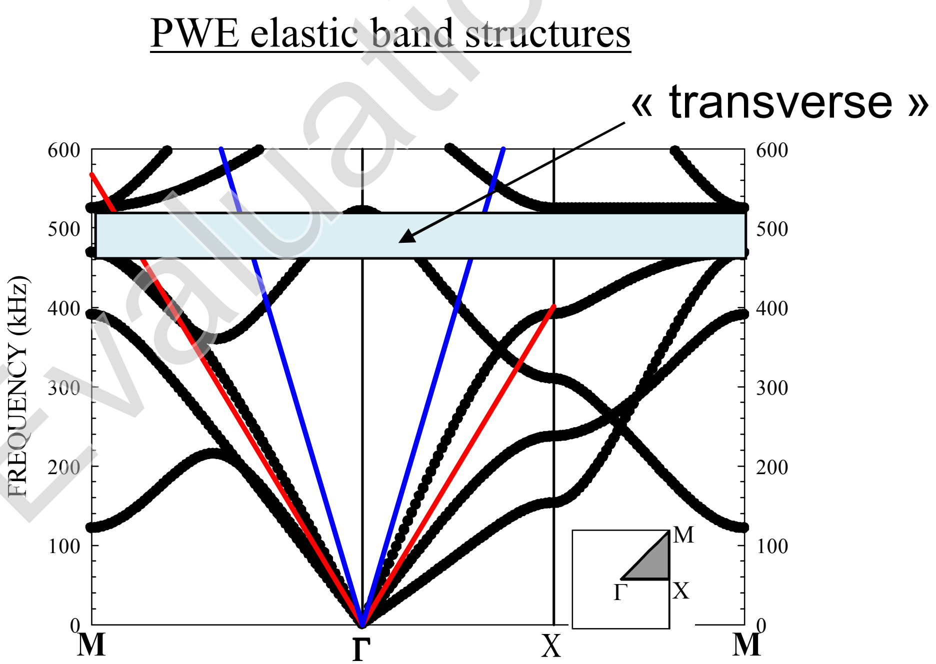
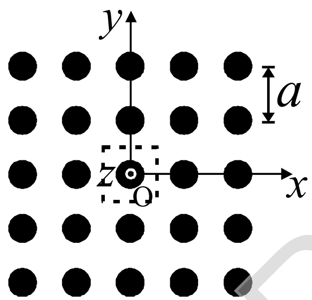
[2]*Department of Physics, Wuhan University, Wuhan 430072, People's Republic of China*
(Received 30 August 2007; published 16 January 2008)



Réfraction négative d'une onde transversale



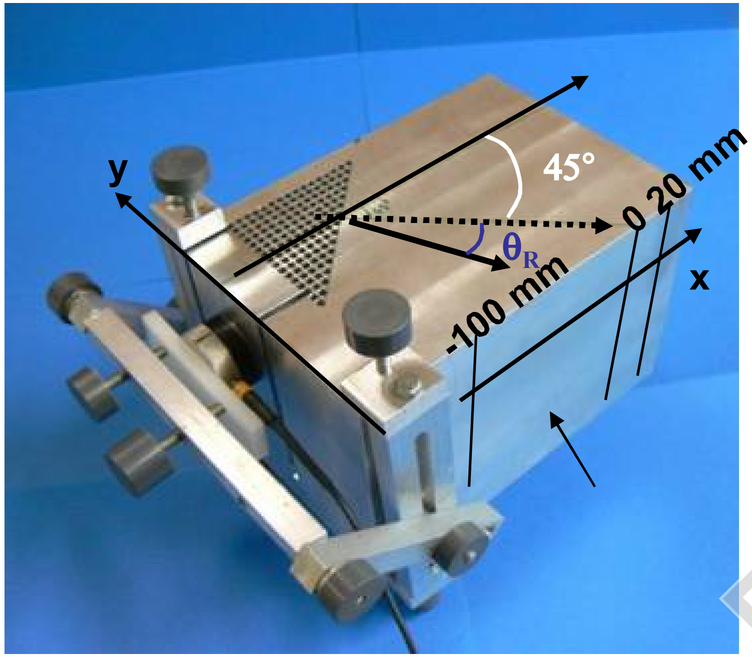




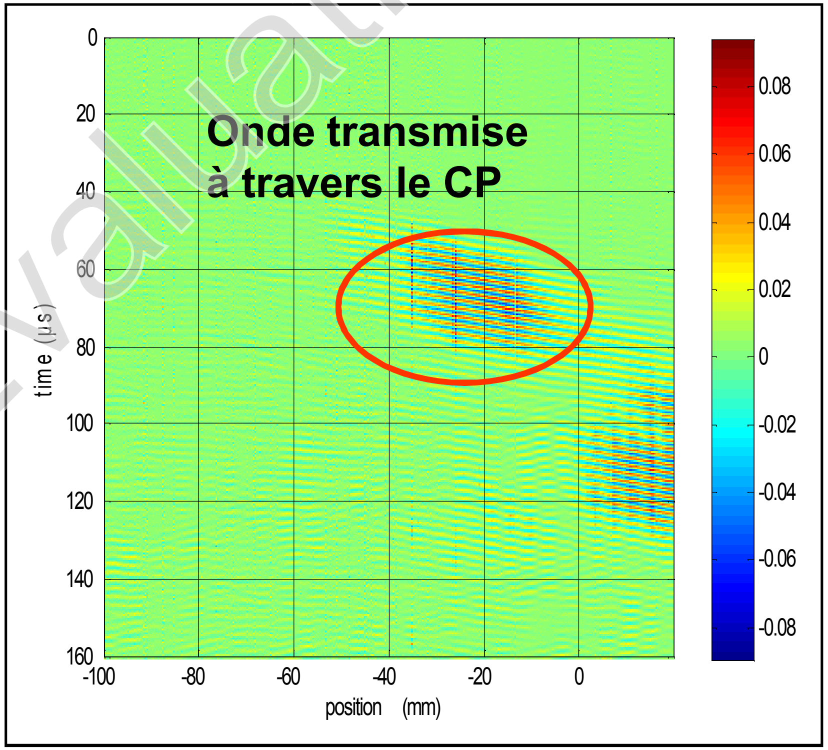
a = 3.9 mm
Rayon des trous = 1.6 mm

Objectif : étudier le phénomène de réfraction négative dans un milieu solide.

Réfraction négative d'une onde transversale



Un vibromètre laser Polytec® (VD09) est utilisé pour mesurer les déplacements normaux en surface le long de l'axe x. L'échantillon est translaté par pas de 0.2 mm



$k_{T\text{-}alu} \sin\theta_R = k_{pc} \sin \theta_{pc}$

$k_{T\text{-}alu}$ ↓ 963.5m^{-1} ; k_{pc} ↓ -186 m^{-1} ; $\sin\theta_{pc}$ → $\frac{\sqrt{2}}{2}$

Angle de réfraction théorique à F= 480kHz

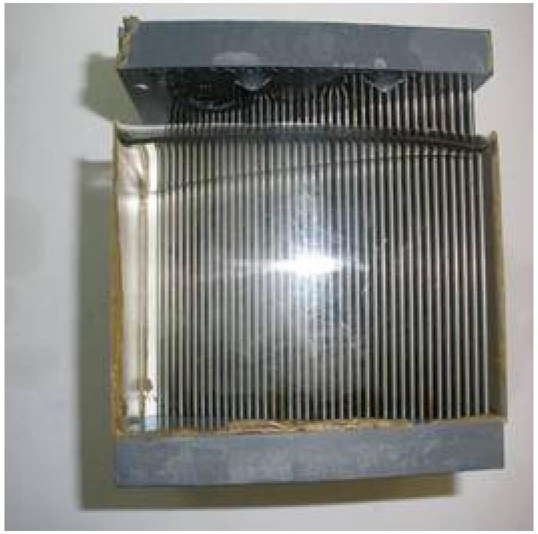
➔ $(\theta_R)_{theo} \sim -\ 7.85°$

Angle de réfraction expérimental à F= 480kHz

➔ $(\theta_R)_{exp} \sim -\ 5°$

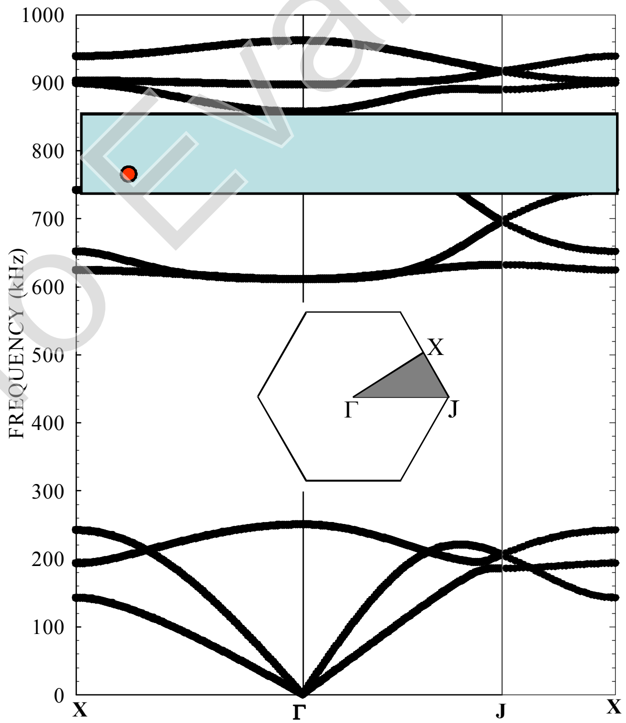
Dans le CP, très grandes longueurs d'onde (de l'ordre de 30mm) à comparer au paramètre de maille a=3.9mm !!!

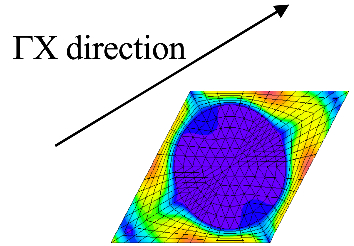
Réfraction négative d'une onde longitudinale



Résine époxy coulée dans le réseau de tiges d'acier inox (rayon 1mm)

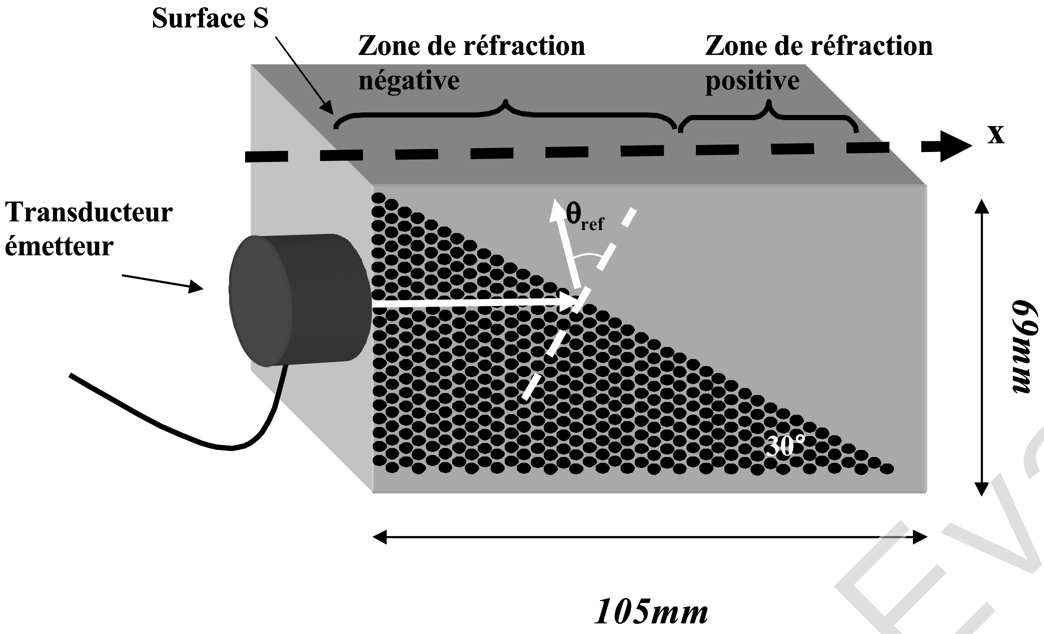
Structure de bande du CP 2D. Réseau triangulaire (a=2.84mm) de cylindres d'acier dans une matrice époxy.



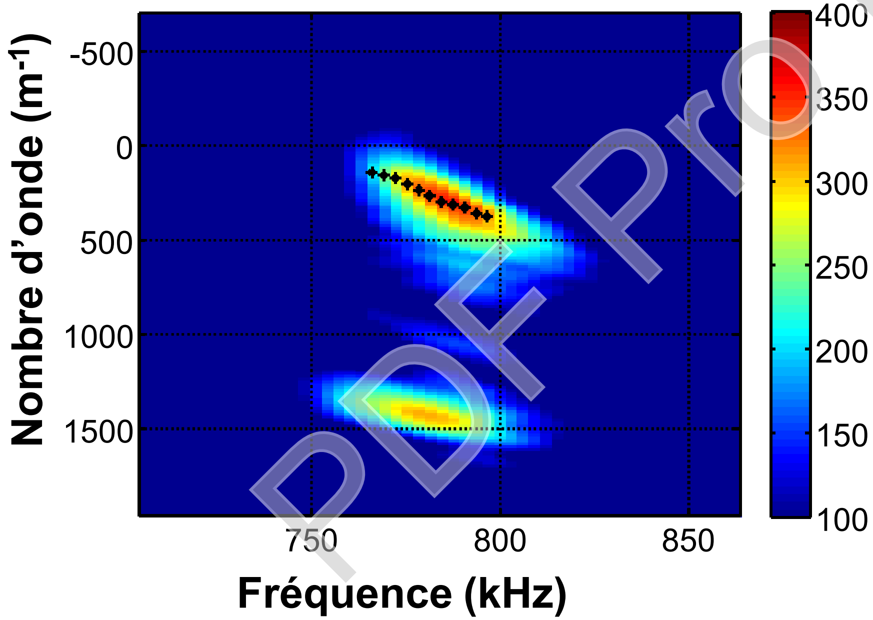


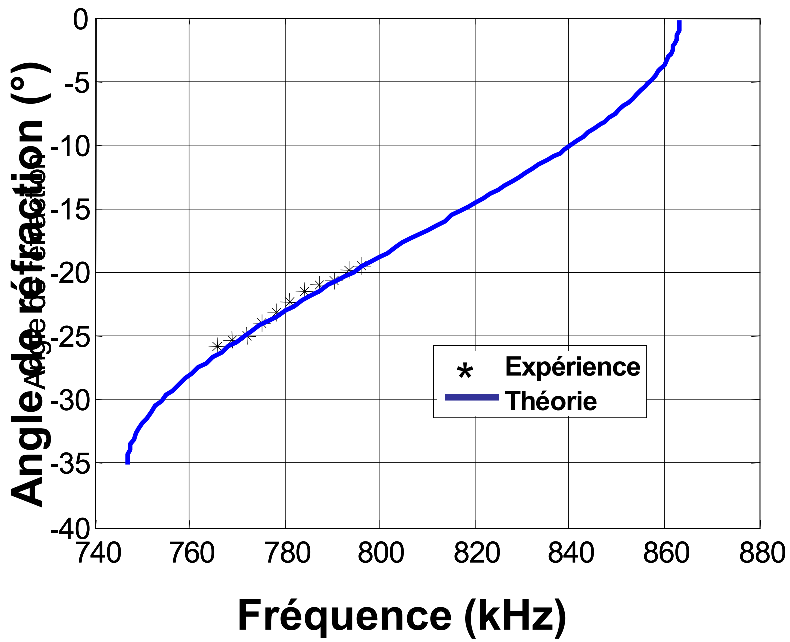
Champ de déplacement dans le CP pour k = 900 m^{-1} et f = 780 kHz

Réfraction négative d'une onde longitudinale



Dans la bande de fréquence étudiée la plus grande longueur d'onde dans le CP est de l'ordre de 4mm, la distance parcourue dans le CP est donc de l'ordre de 10 longueurs d'onde.





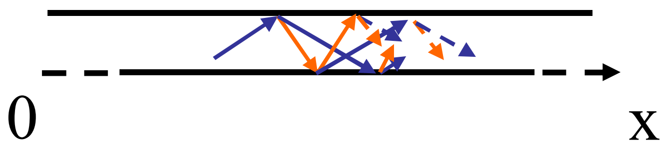
Lamb waves with opposite group and phase velocities in a plate with periodic corrugation

• Laboratoire d'Acoustique de l'Université du Maine (LAUM UMR CNRS 6613).
Catherine Potel, Claude Depollier et Michel Bruneau

• Institut d'Electronique, de Microélectronique et de Nanotechnologie, IEMN UMR CNRS 852.
Anne Christine Hladky, Bertrand Dubus, Jérôme Vasseur

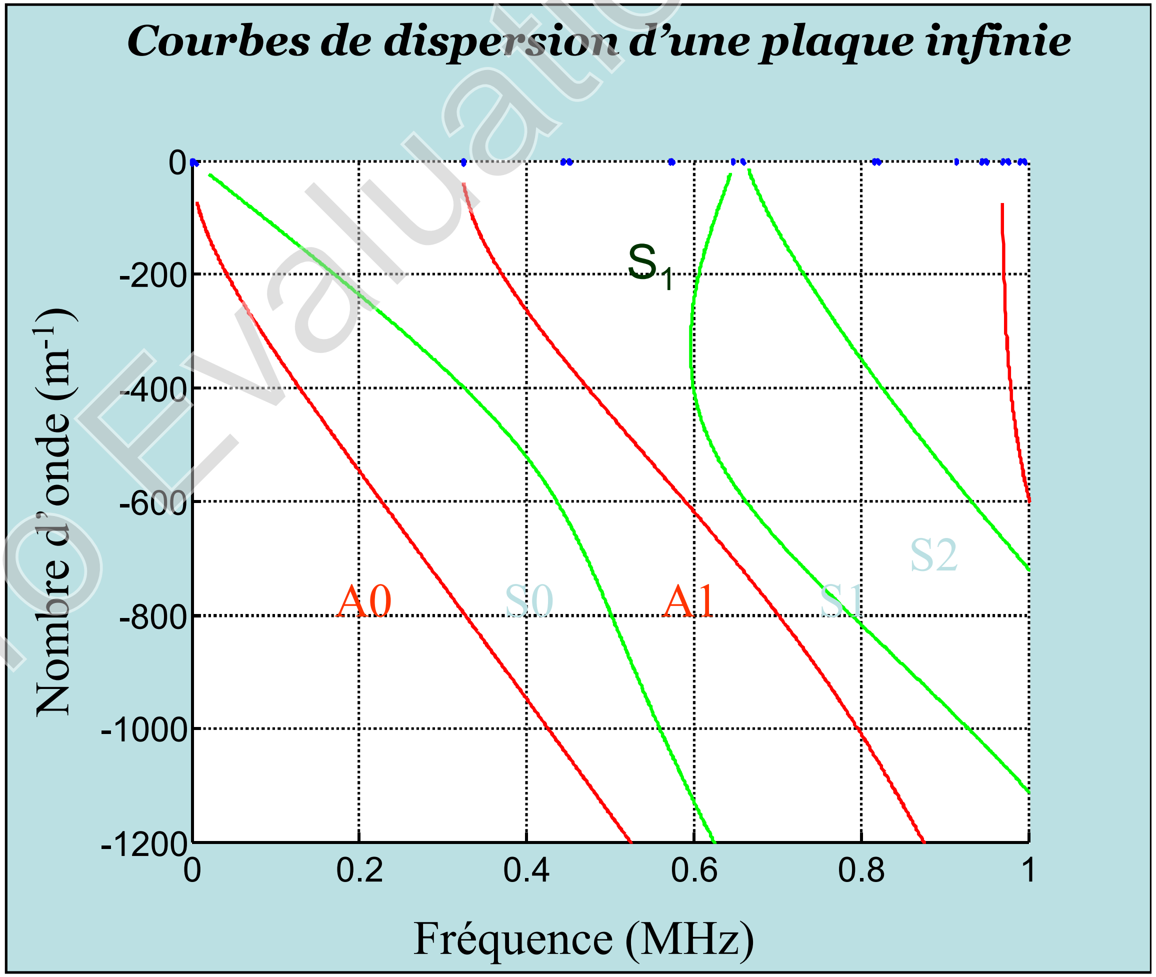
Lamb waves with opposite V_g and V_ϕ

Plaque infinie surfaces planes



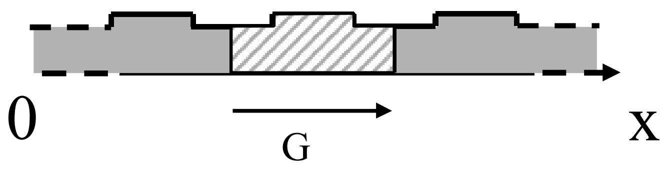
Epaisseur de la plaque
E=5mm

Couplage modal associé à l'ouverture d'une bande interdite Ondes de Lamb



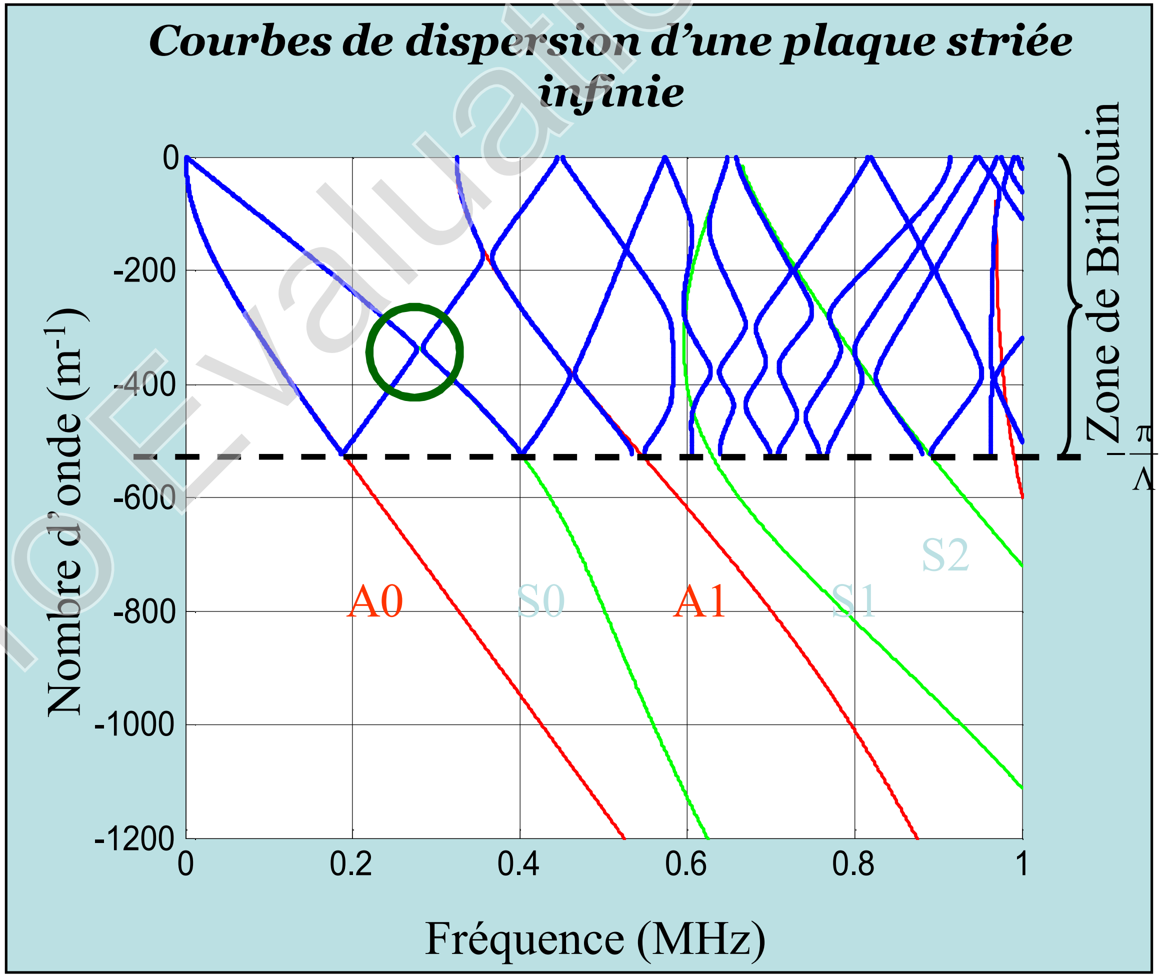
Lamb waves with opposite V_g and V_ϕ

Plaque avec réseau de surface

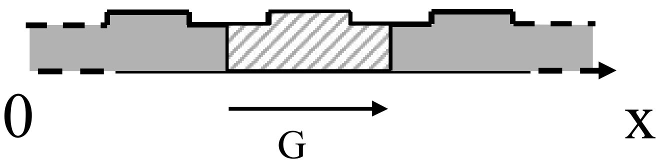


Epaisseur de la plaque E=5mm

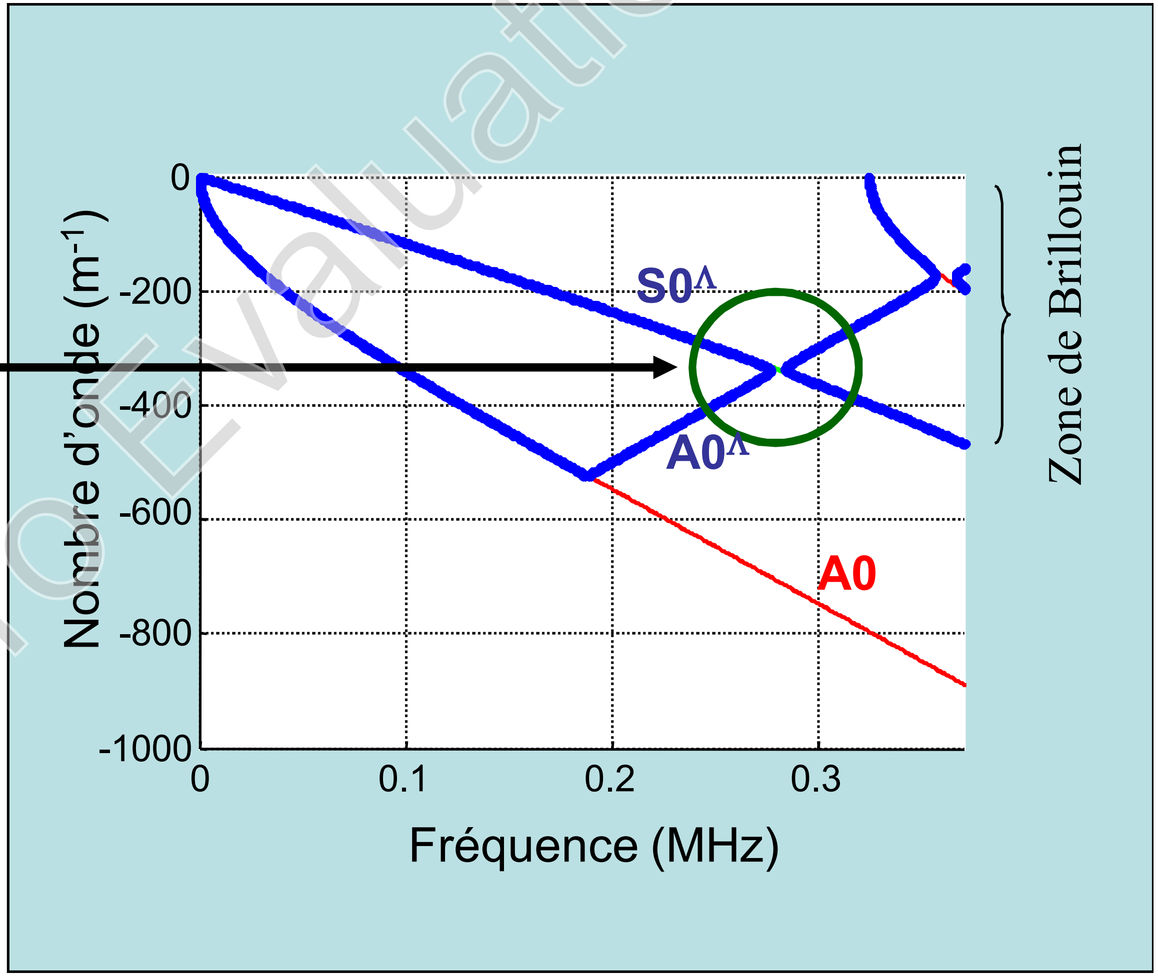
Profondeur des stries p=200µm



Lamb waves with opposite Vg and V_ϕ



Couplage des modes A0 et S0



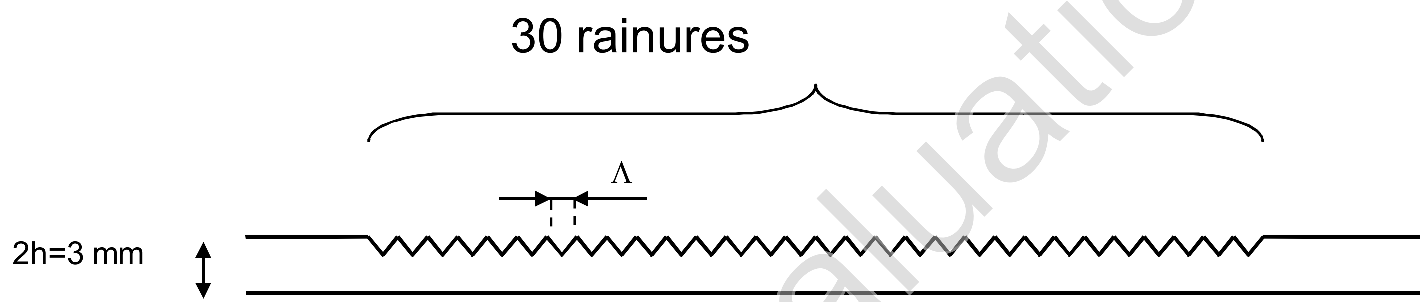
$$-\mathbf{k}_{A0} = \mathbf{k}_{S0} - \mathbf{G}$$

Avec G vecteur de base du réseau réciproque défini par

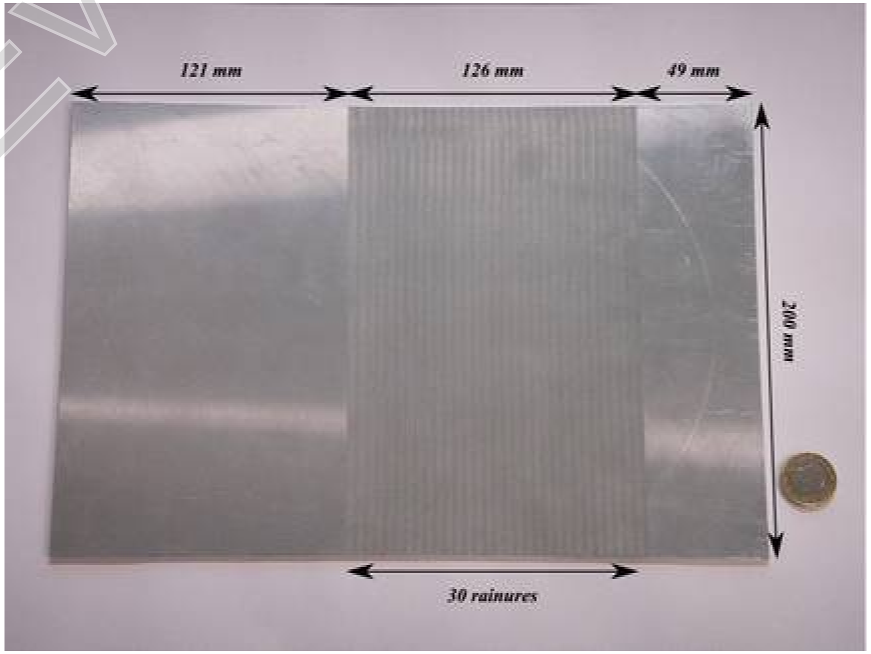
$$G = \frac{2\pi}{\Lambda} u_x$$

Lamb waves with opposite V_g and V_ϕ

- **Sample presentation**

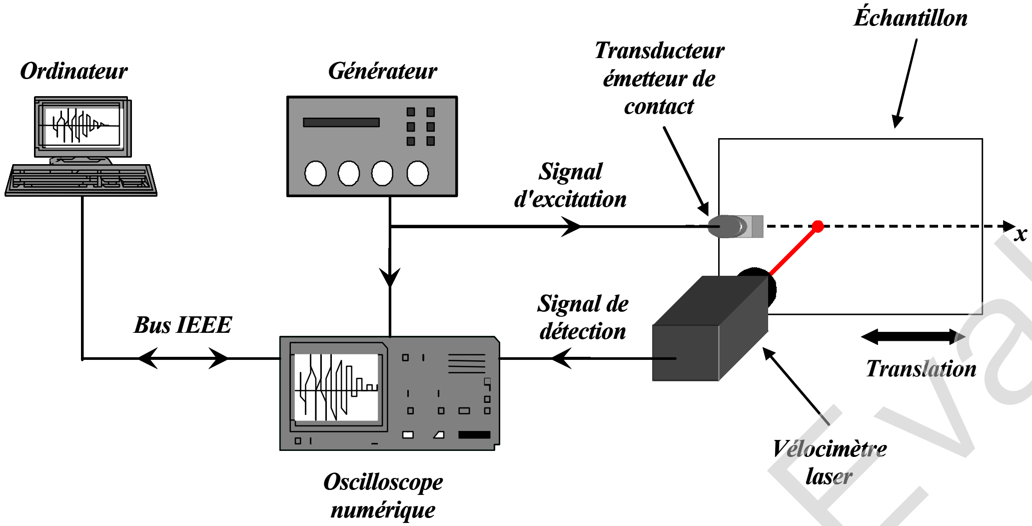


Plaque d'aluminium
+ réseau de stries triangulaires
Profondeur = 120 µm
Période spatiale Λ = 4.2 mm

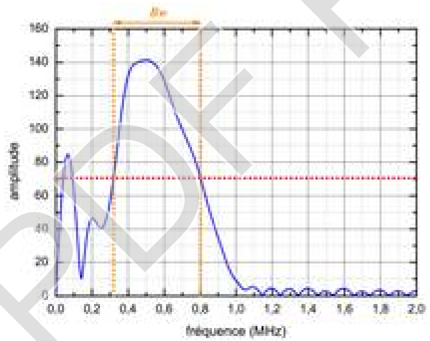


Lamb waves with opposite V_g and V_ϕ

Expérimental set up

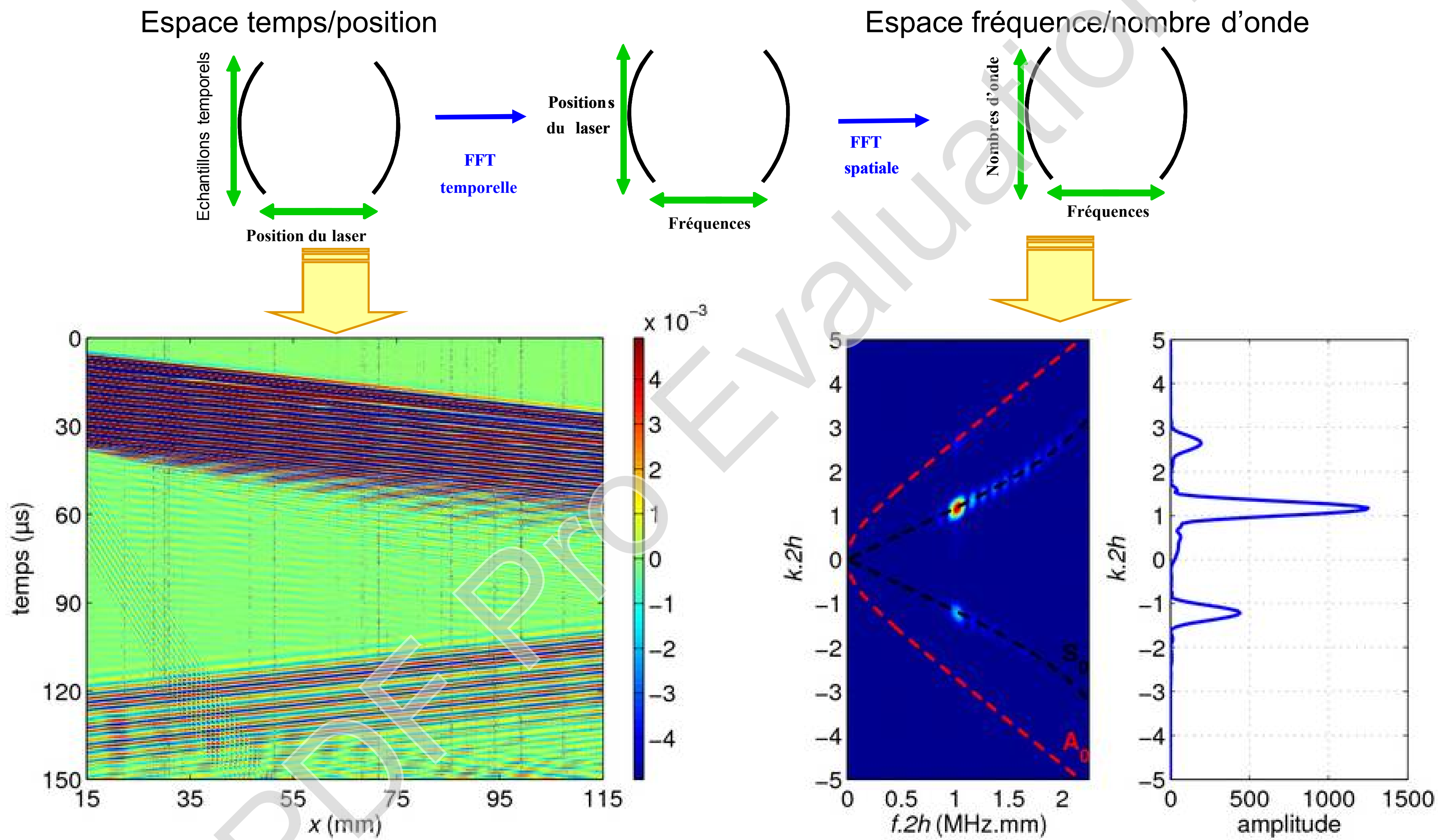


Émission : Transducteur Panametrics (f=500kHz)
Réception : Laser POLYTEC® OFV-505 + decodeur VD09 calibre 20 mm/s/V (fréquence max 1MHz)



Lamb waves with opposite V_g and V_ϕ

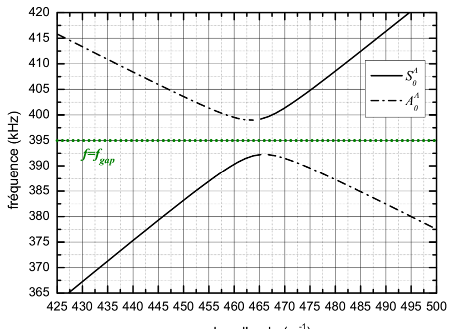
- **Plate without corrugation**

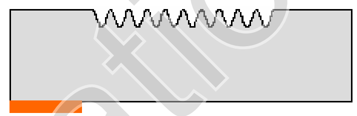


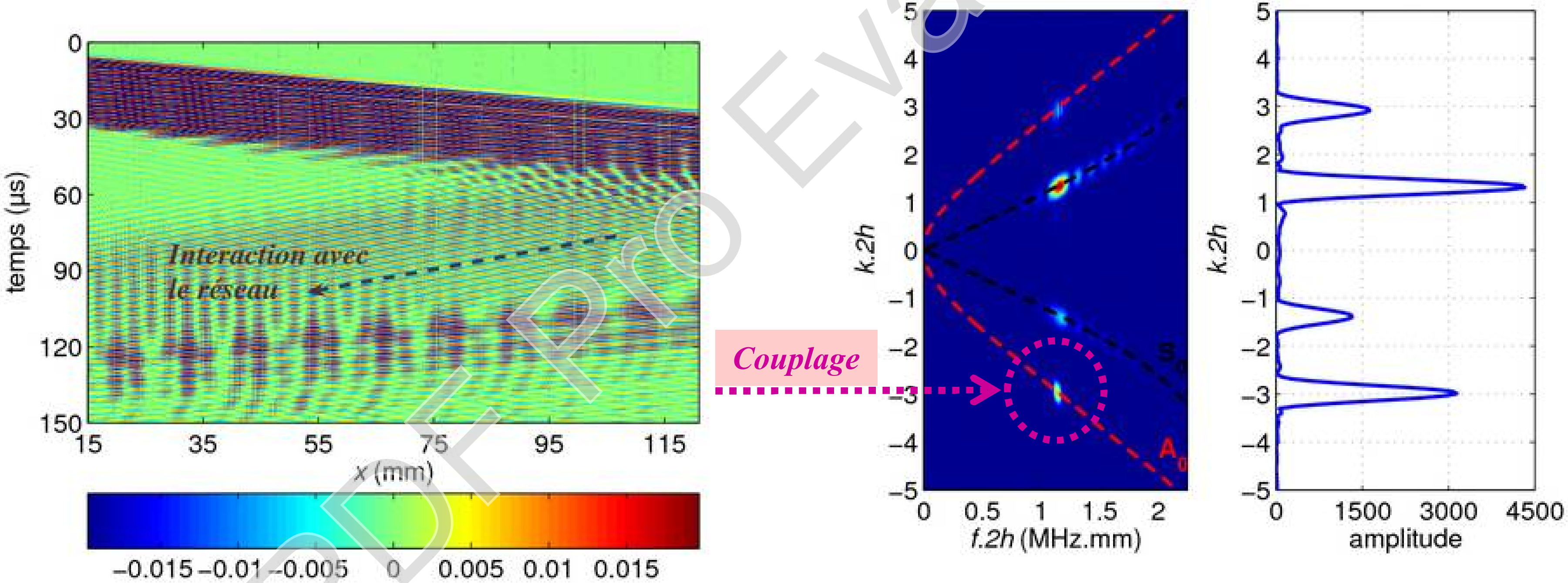
Lamb waves with opposite V_g and V_ϕ

• **Plate with corrugation**

• **Plaque striée : Propagation avant le réseau à $f \approx f_{gap}$**

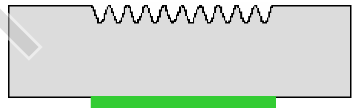




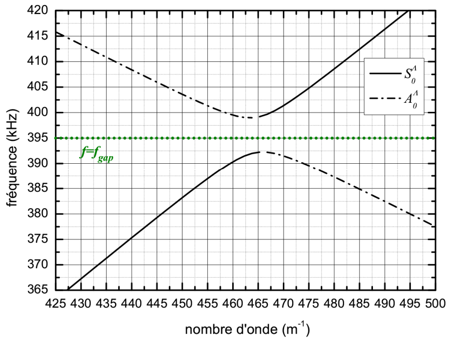


Lamb waves with opposite Vg and V_ϕ

- **Plate with corrugation**

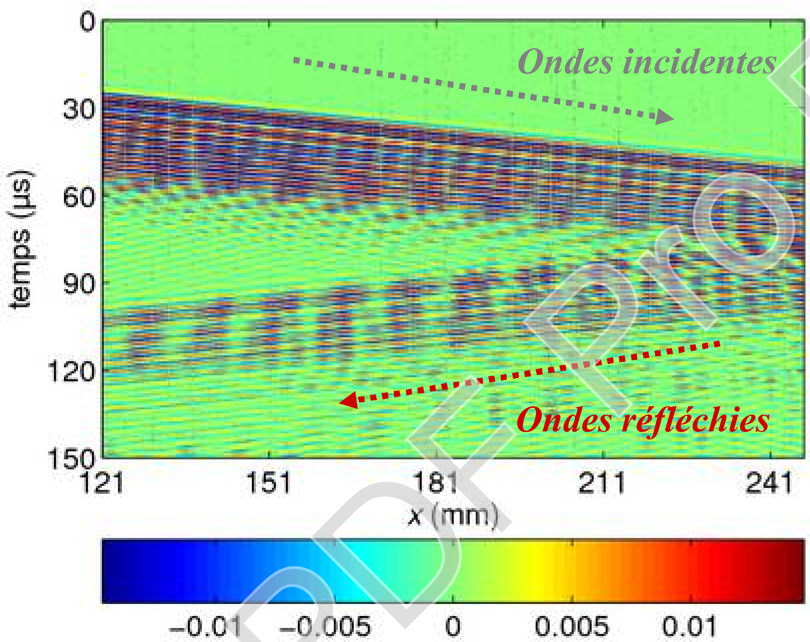


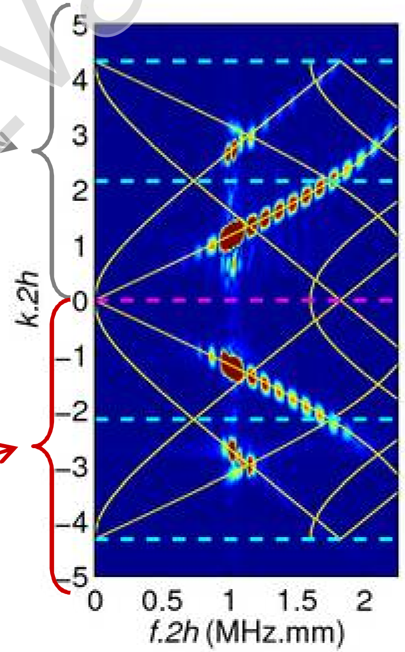
- **Plaque striée : Propagation sous le réseau à f < fgap**

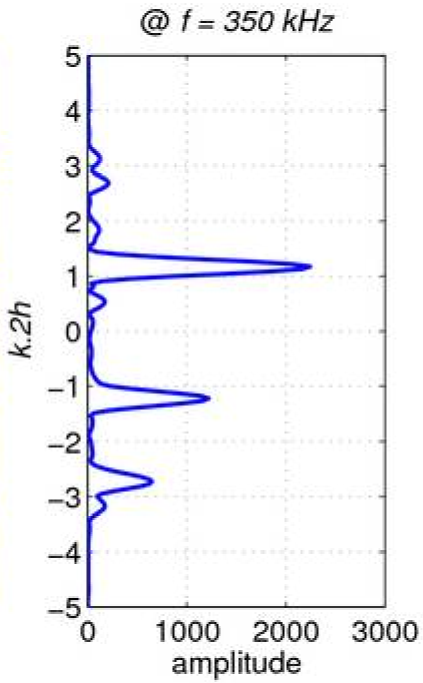


Identification de pseudo-modes de Lamb

Ondes incidentes





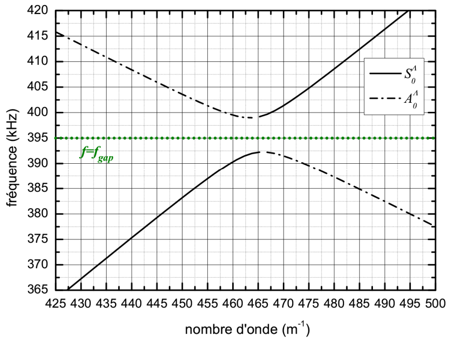


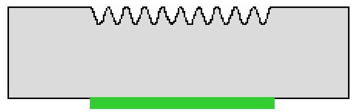
Ondes réfléchies

Lamb waves with opposite Vg and V_ϕ

• **Plate with corrugation**

• **Plaque striée : Propagation sous le réseau à f < fgap**





Identification de pseudo-modes de Lamb